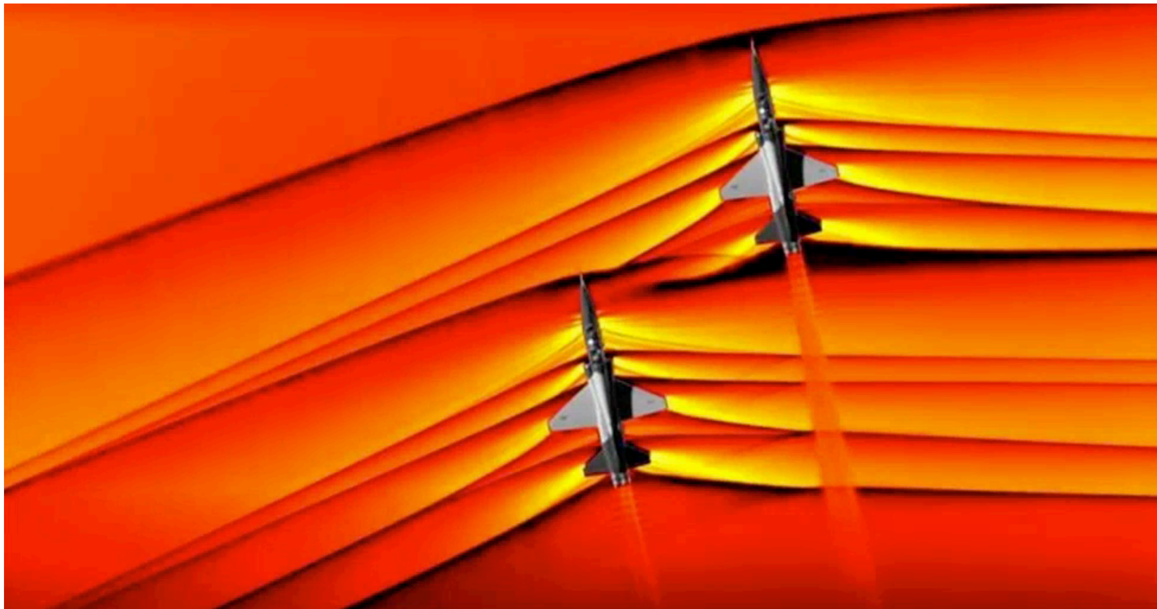

Advanced Modeling and Simulation Symposium Series

NASA Ames Research Center

February 11th 2021

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The Impact of Multi-Physics CFD Simulation in Aircraft Safety and Droplet Modeling

Dr. Durrell Rittenberg, Director of Aerospace and Defense Siemens DISW Simcenter
Prashanth Shankara, Sr. Product Marketing Manager

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Key Trends
Aerospace and Defense

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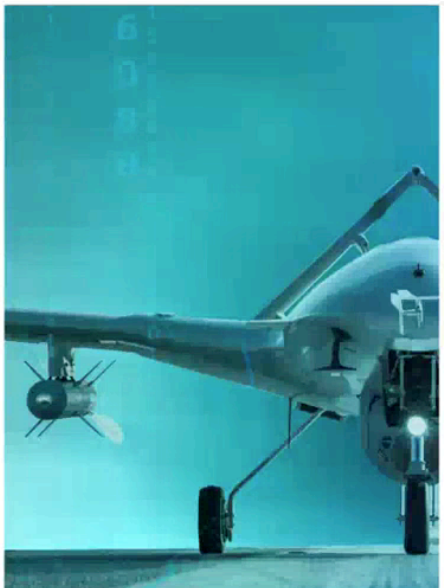
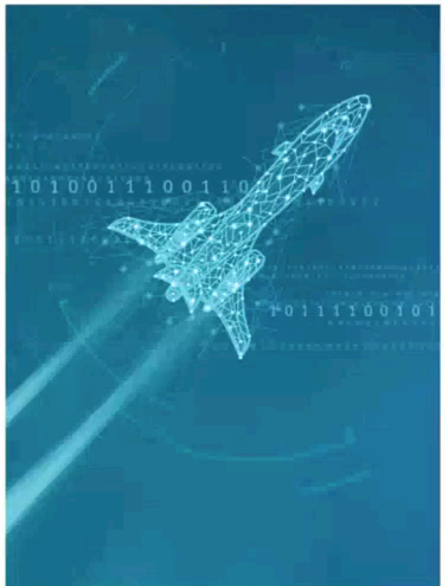
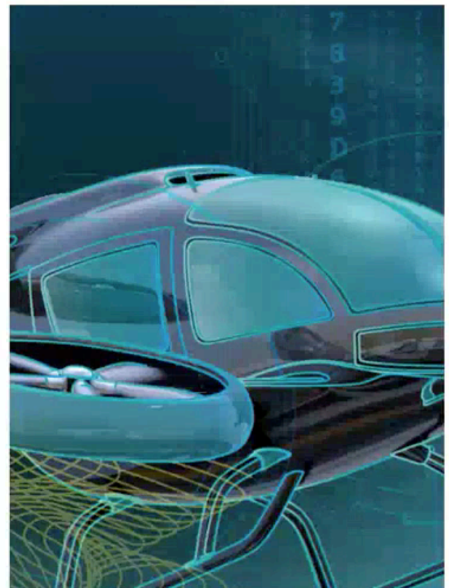


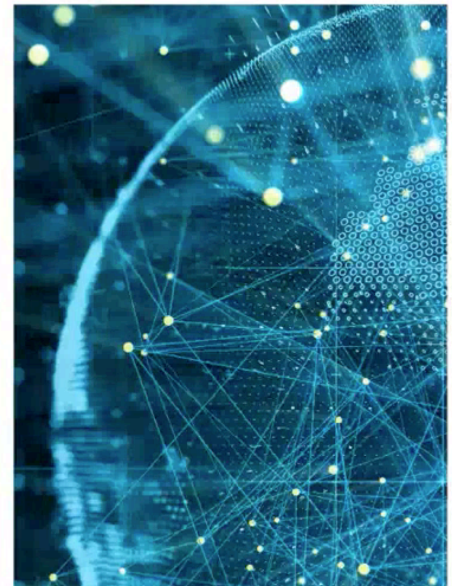
Pressure to Reduce Program Cost and Schedule



Increasing Program Complexity and Integration

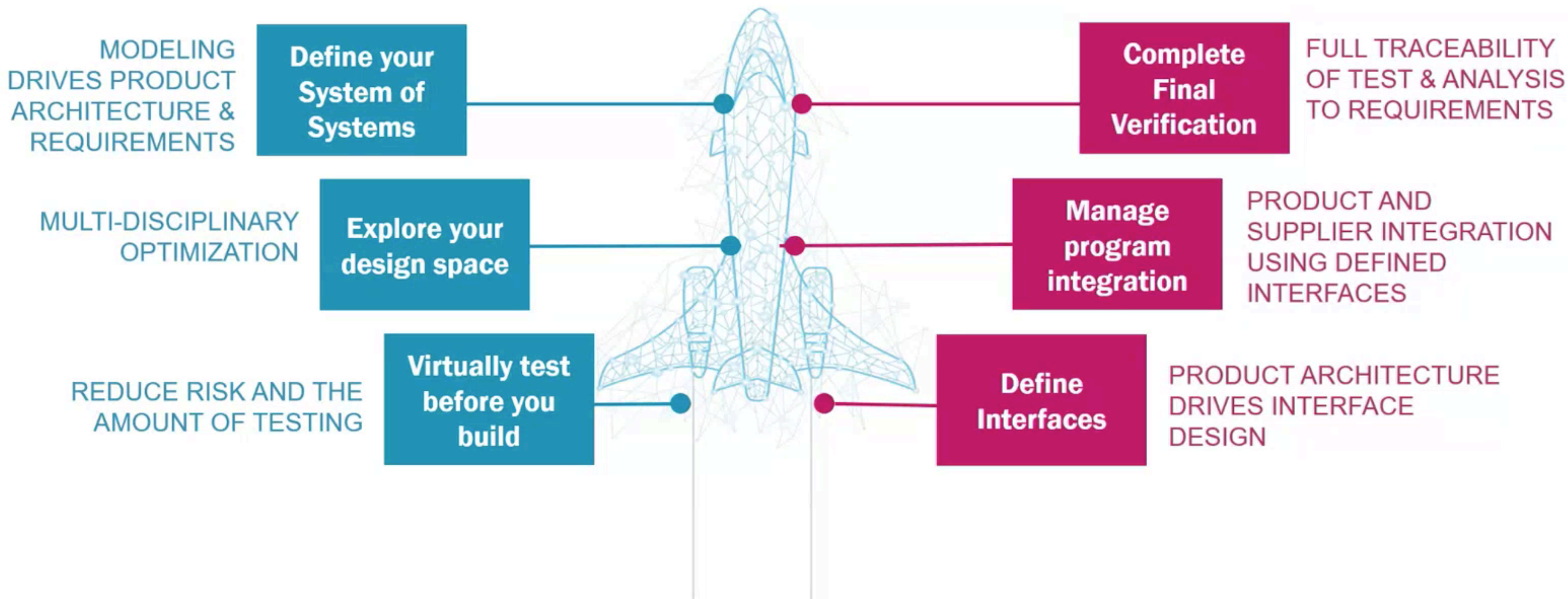


Increased Electrification of Products



Globalization

Digital Thread – Improving Program Execution



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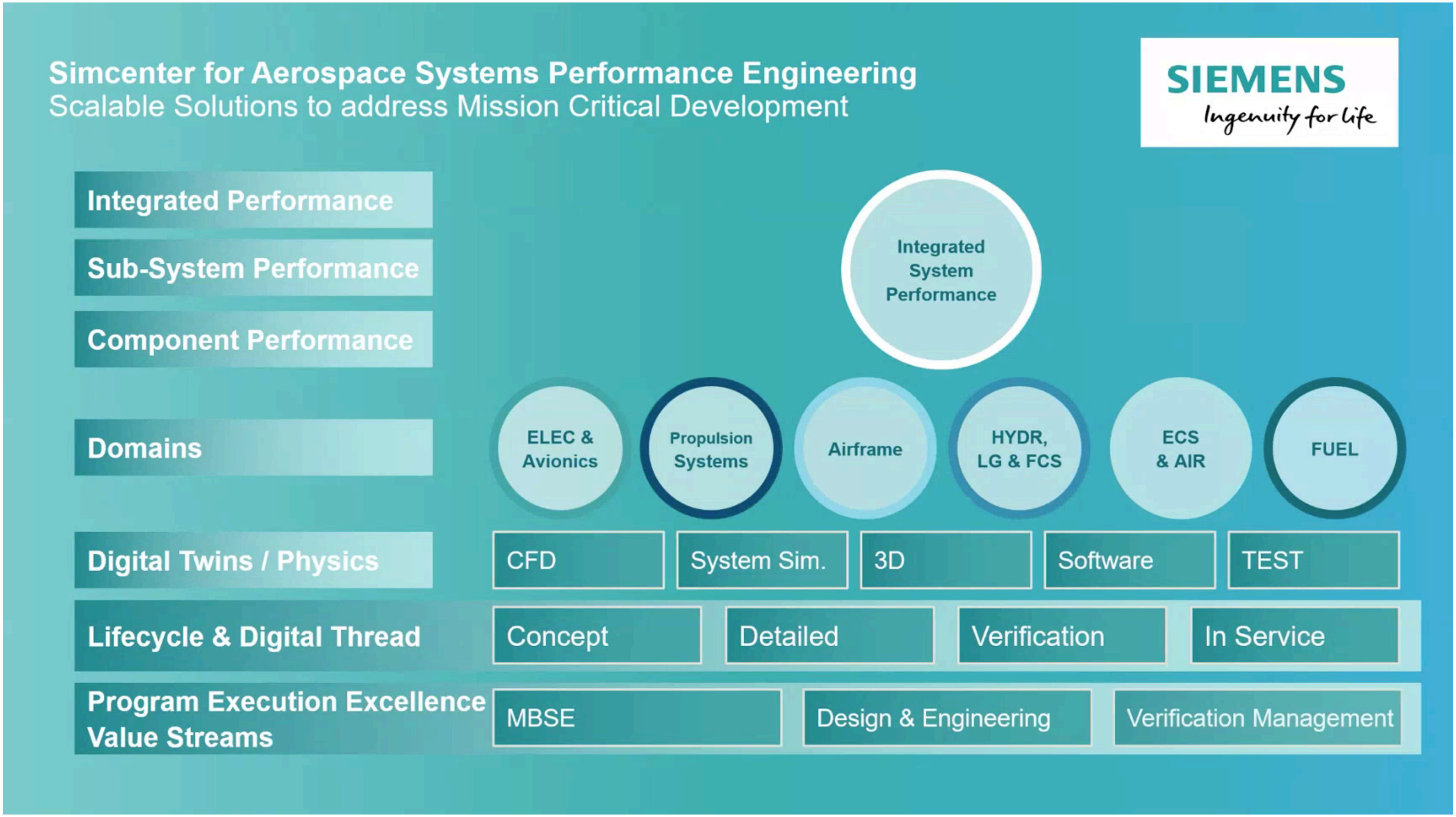
Simcenter for Aerospace Systems Performance Engineering
Scalable Solutions to address Mission Critical Development
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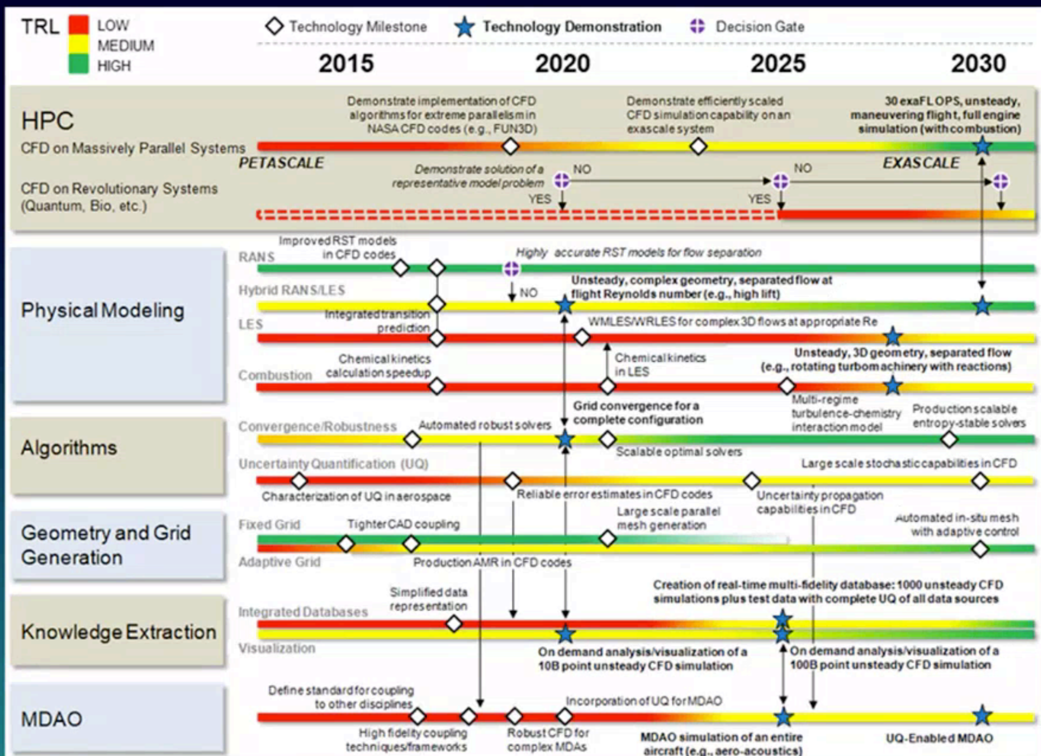
Integrated Performance
Sub-System Performance
Component Performance
Integrated System Performance
Domains
ELEC & Avionics
Propulsion Systems
Airframe
HYDR, LG & FCS
ECS & AIR
FUEL
Digital Twins / Physics
CFD
System Sim.
3D
Software
TEST
Lifecycle & Digital Thread
Concept
Detailed
Verification
In Service
Program Execution Excellence Value Streams
MBSE
Design & Engineering
Verification Management

Siemens Simcenter supporting AIAA and the broader community



- CFD 2030 guiding our development direction and priorities
- AIAA Workshops
  - DPW, HLPW, PAW, WIPP
  - Transition Modeling
  - Hover prediction
  - Sonic Boom
- Committees
  - EATS
  - IPW (ASME)
  - INPSI
- Research programs
  - Clean Skies (1, 2, 3)
  - LUFO
  - Multiple SBIR (corrosion)

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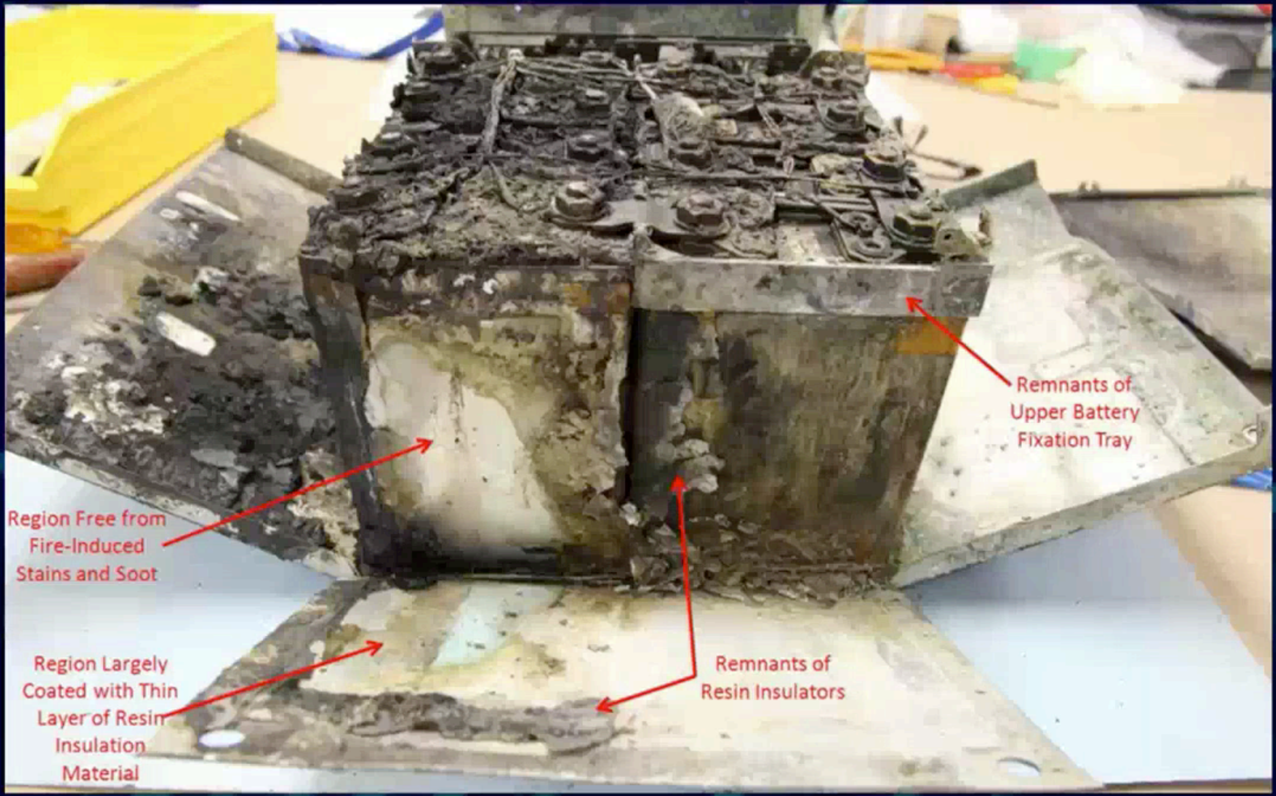
Multiphysics simulation for Battery safety

Challenge

- Ensure safe containment during thermal runaway – failure in one cell propagates.
- Regulation en route. Key for brand.
- Complex multiphysics problem (multiphase, reactions, thermal radiation, FSI, phase change, ...)

Solution

- Multiphysics prediction cell failure and runaway used to design containment strategy.



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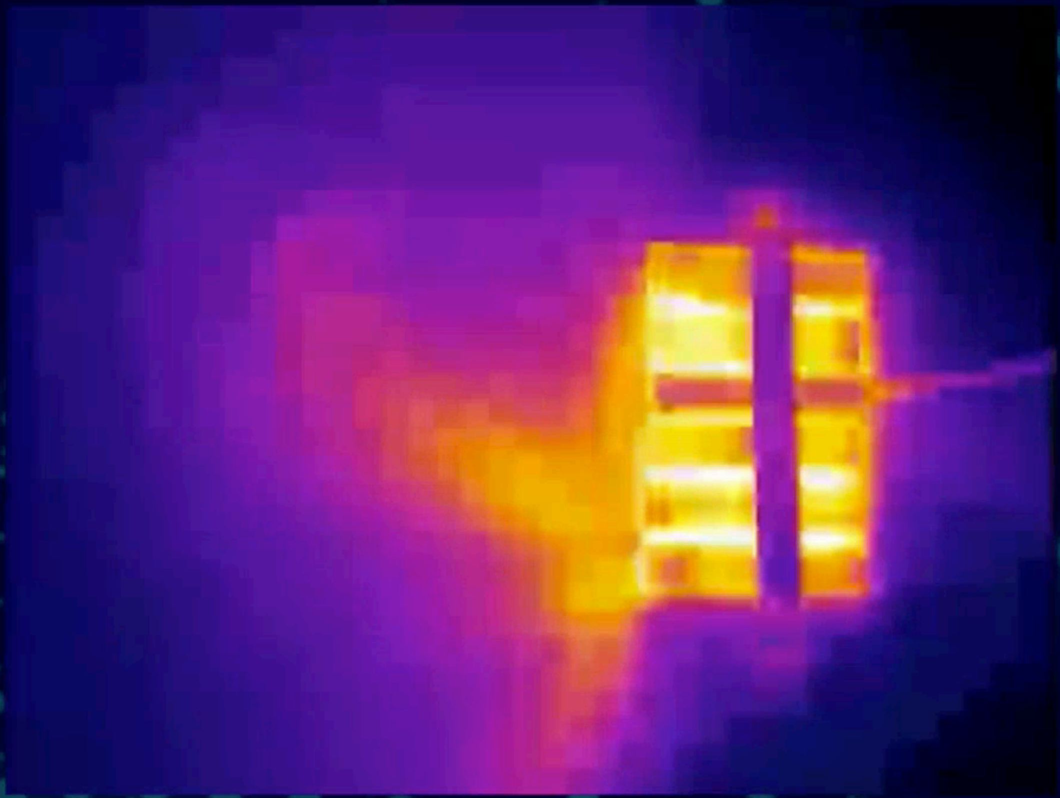

Cold weather flight in UAM

Challenge

- Impact of energy use
- Avoiding ice formation
- Sensor location planning
- Design of protection systems

Solution

- Multi-phase predictions of real world conditions?
- Understanding heat transfer
- Ice formation and aerodynamic performance

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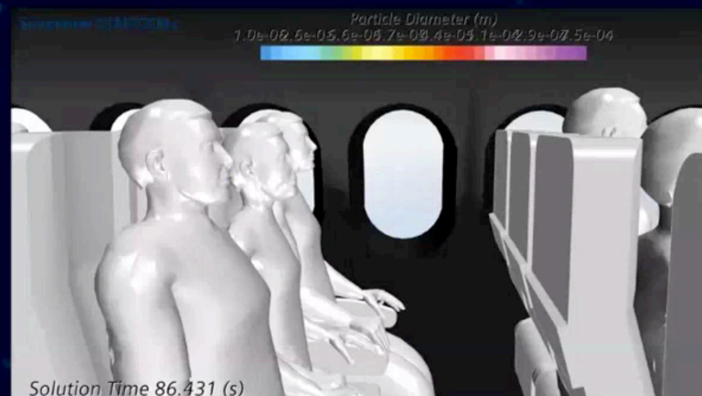
Safe cabin environments

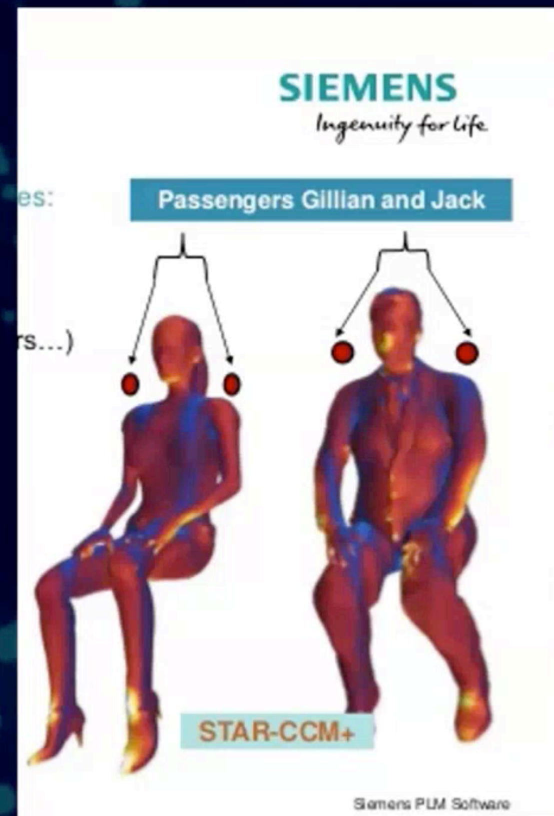
Challenge

- Design ECS systems to ensure comfort and safety
- Certify airflow and filtration
- Certify seat design
- Reduce unwanted noise



Solution

- Multiphase simulation and droplet simulations
- Acoustic testing and simulation
- Thermal comfort models for cabin design



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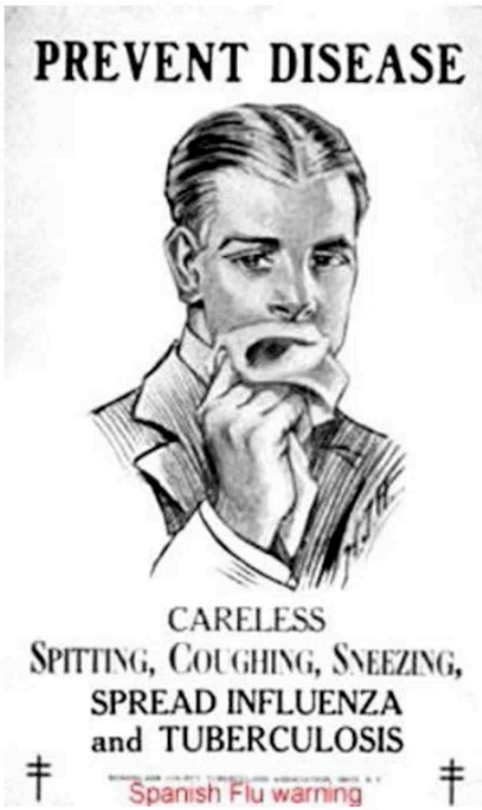
High-fidelity cough simulation in an aircraft cabin
Prashanth Shankara – Siemens Digital Industries Software
Unrestricted © Siemens AG 2020
Engineer innovation.

The human cough
Source of transmission for airborne infections



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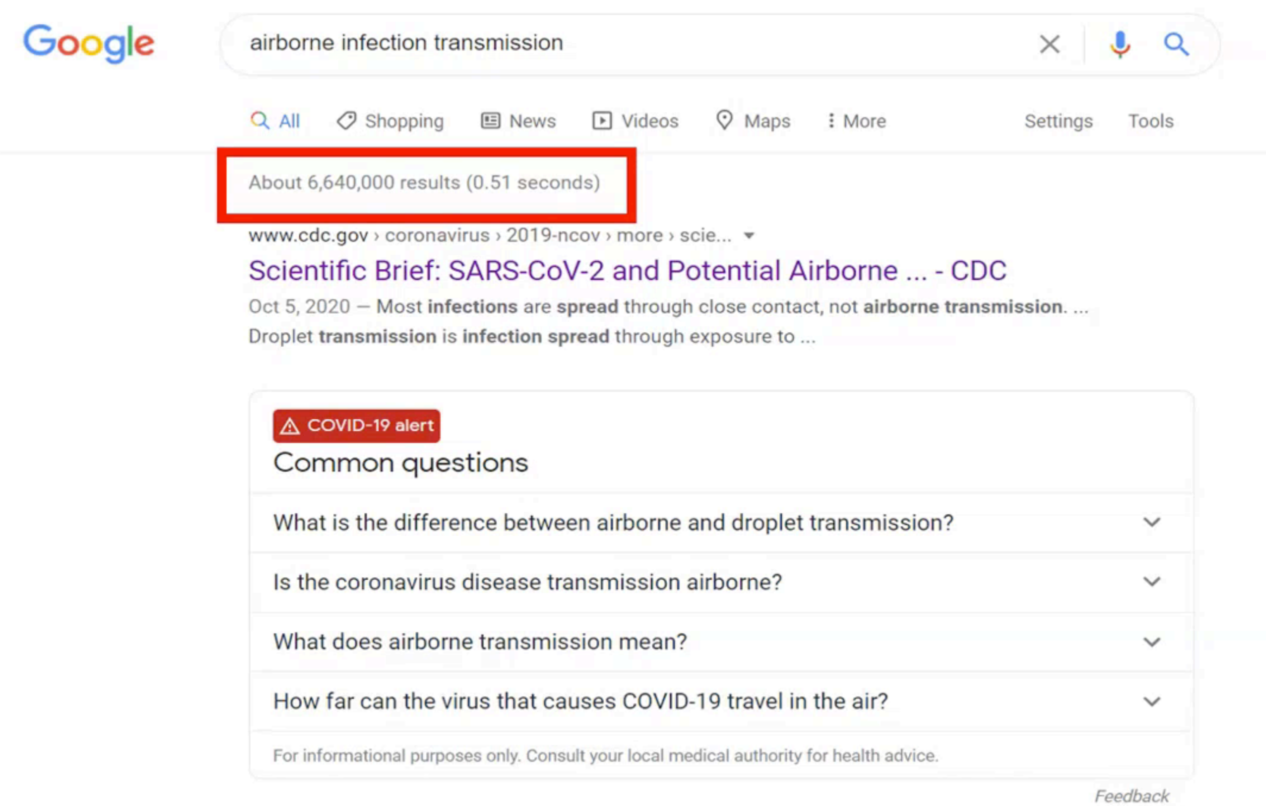

The human cough
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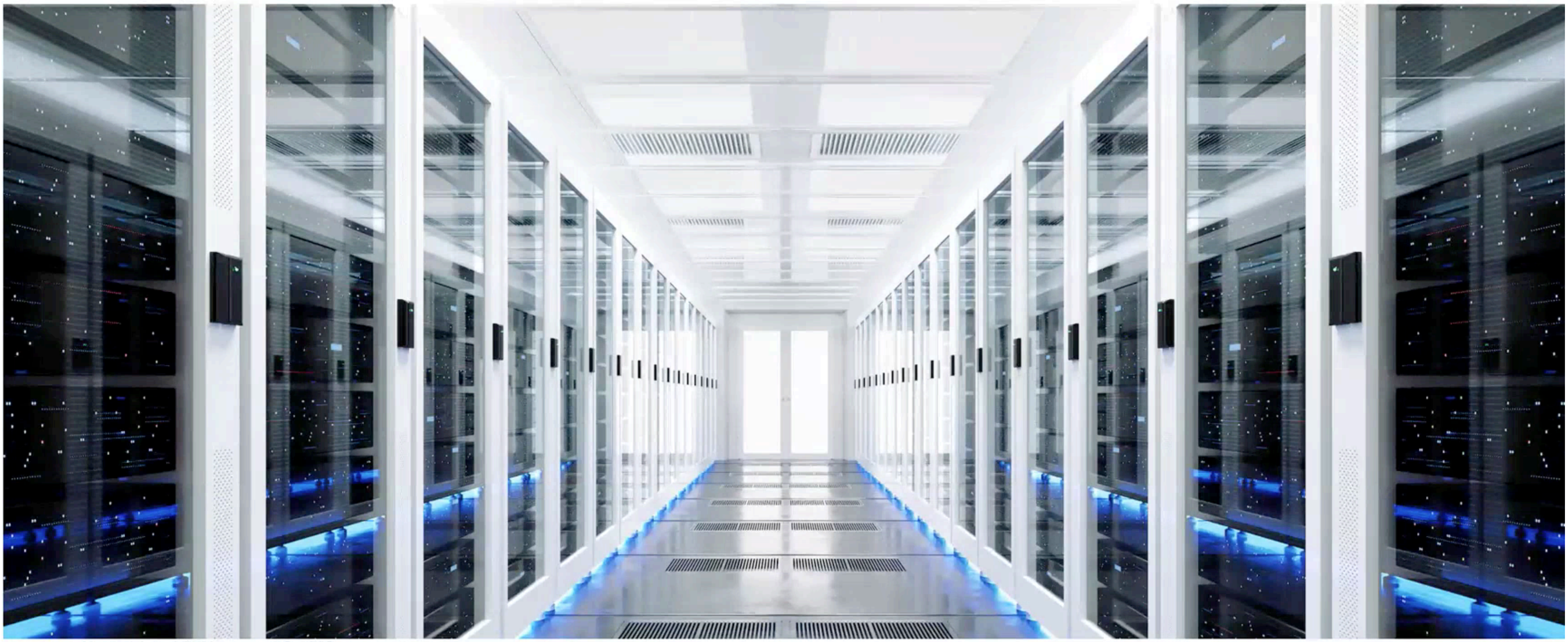

The human cough
Source of transmission for airborne infections

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Understanding the human cough is critical to evaluating transmission risk

The human cough

Source of transmission for airborne infections

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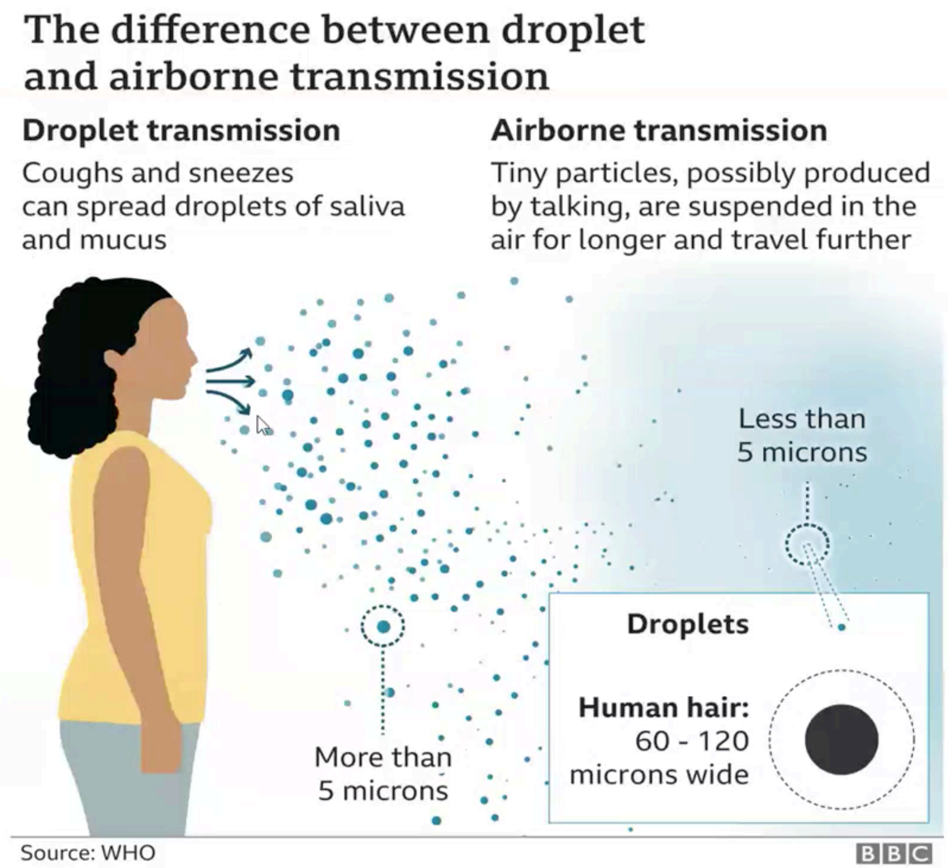
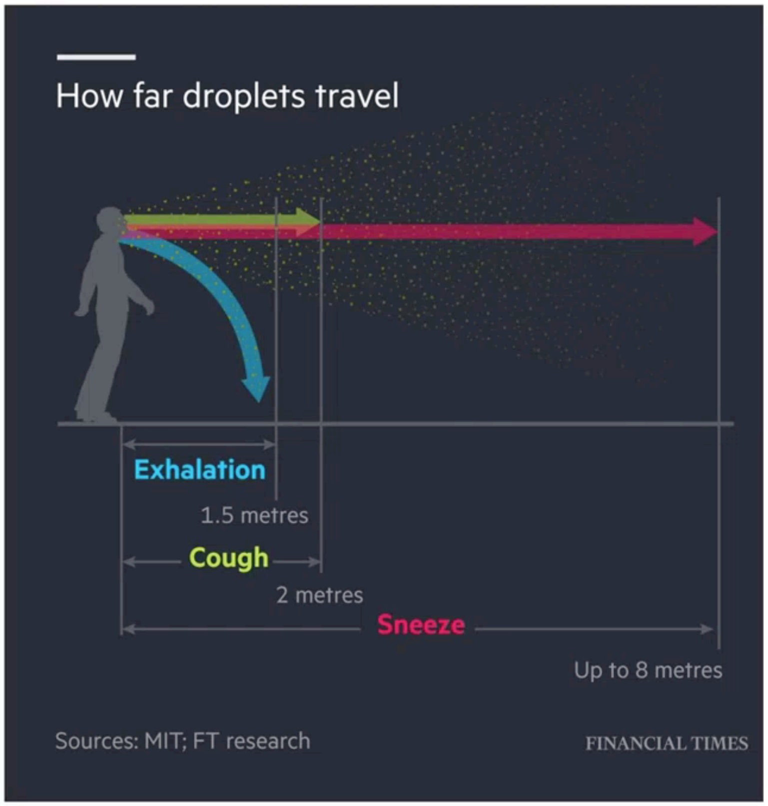
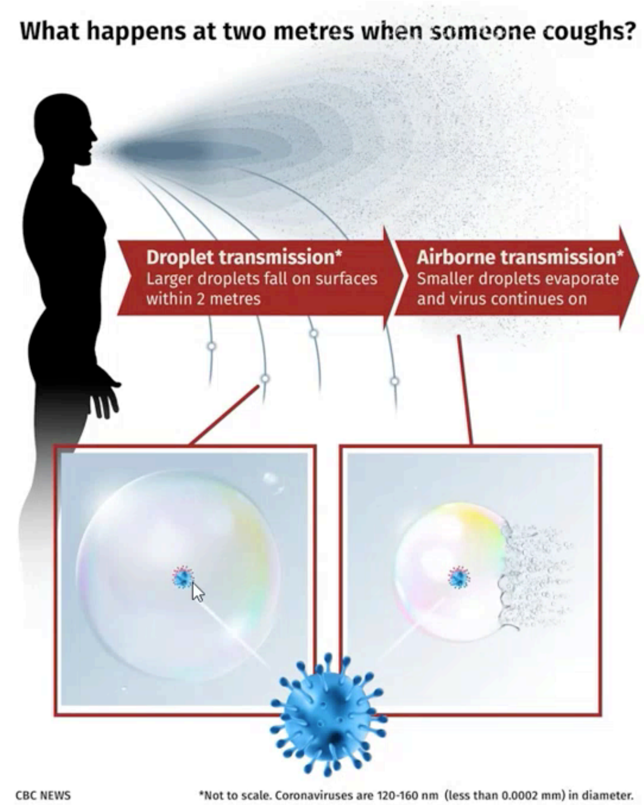
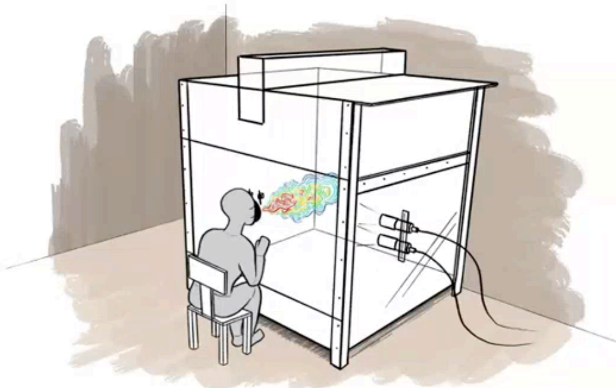


How far do cough droplets travel?
Source of transmission for airborne infections



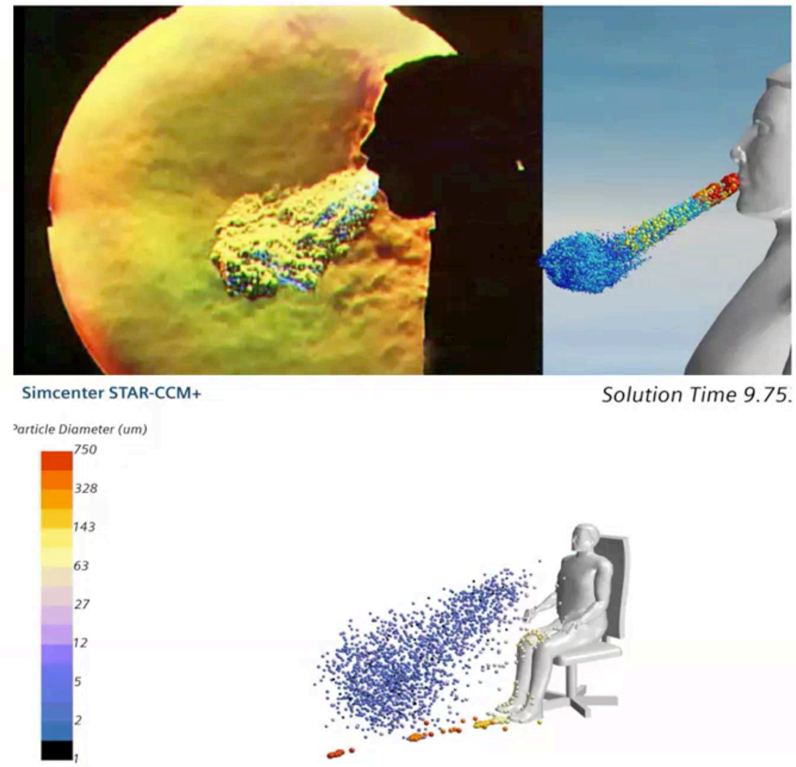


Designing safer indoor environments
Test vs simulation (1 vs 100 design scenarios)



Source: Western University

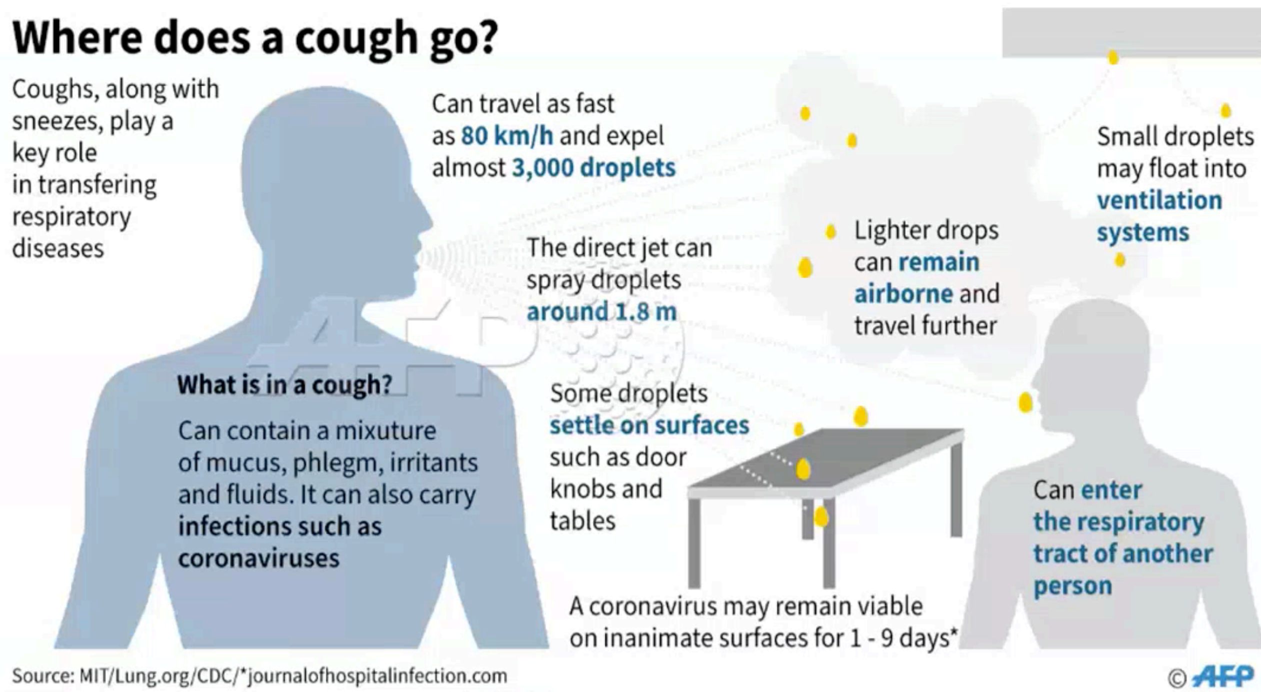
Source: NIOSH

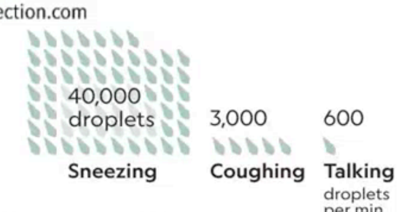


Transport from an infected person

What affects the droplets and where they go?

- Indoor/outdoor
- Temperature/Humidity
- Air flow in space
- Mouth opening
- And more variables….





Source: www.nationalgeographic.co.uk

Transport from an infected person

What affects the droplets and where they go?

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Indoor/outdoor	Head position	Evaporation
Temperature/Humidity	Into elbow	Human heat plume
Air flow in space	Cough strength	Breathing
Mouth opening	Obstacles in space	No. of droplets
Single vs multiple	Droplet size	And more variables…

Modeling a cough with CFD simulation
The challenges

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The right approach
High-fidelity, multiphysics, simulation tool, physics involved

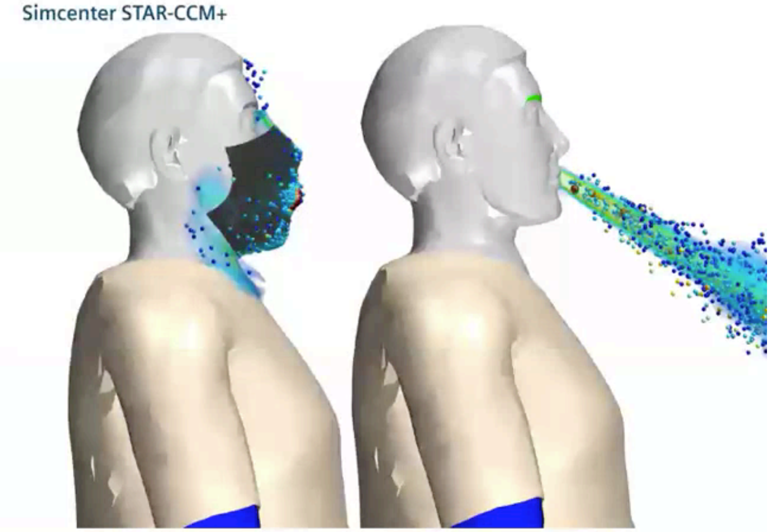
Droplet modeling
Method, size, distribution, angle, mouth opening

Air flow modeling
Unsteady indoor airflow modeled in CFD

Cough jet
Time dependent flow, unsteady

Droplet tracking
Time of tracking, evaporation, breathing, forces on droplet

Different scenarios
Flow, patient, barriers, mask, cough types



Accurately modeling a single cough is incredibly complex. All the representative physics and scenarios need to be accounted for. The exact geometry of the indoor space needs to be modeled.

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Multiphysics CFD simulation software to model cough droplets

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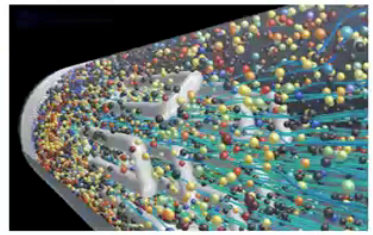
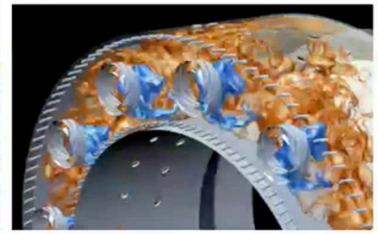
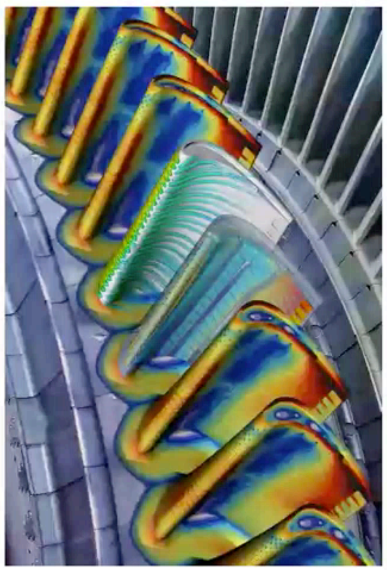
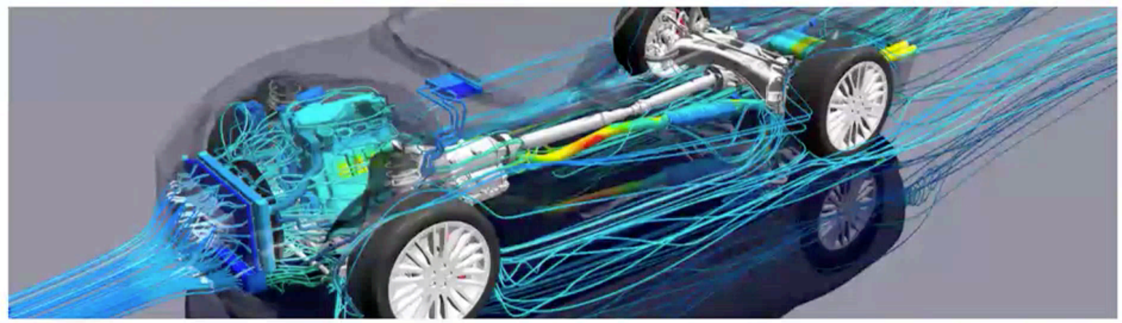
- Fluid dynamics
- Heat transfer
- Engine In-Cylinder
- Aeroacoustics
- Multiphase flows
- Particle flows
- Electrochemistry
- Battery Simulation
- Solid Mechanics
- Design Exploration
- Many more…

Simcenter STAR-CCM+ is the CFD-focused multiphysics engineering solution that uniquely integrates comprehensive physics with intelligent design exploration in a single CAD-to-solution environment, built for the most simple to the most advanced CFD simulation needs.

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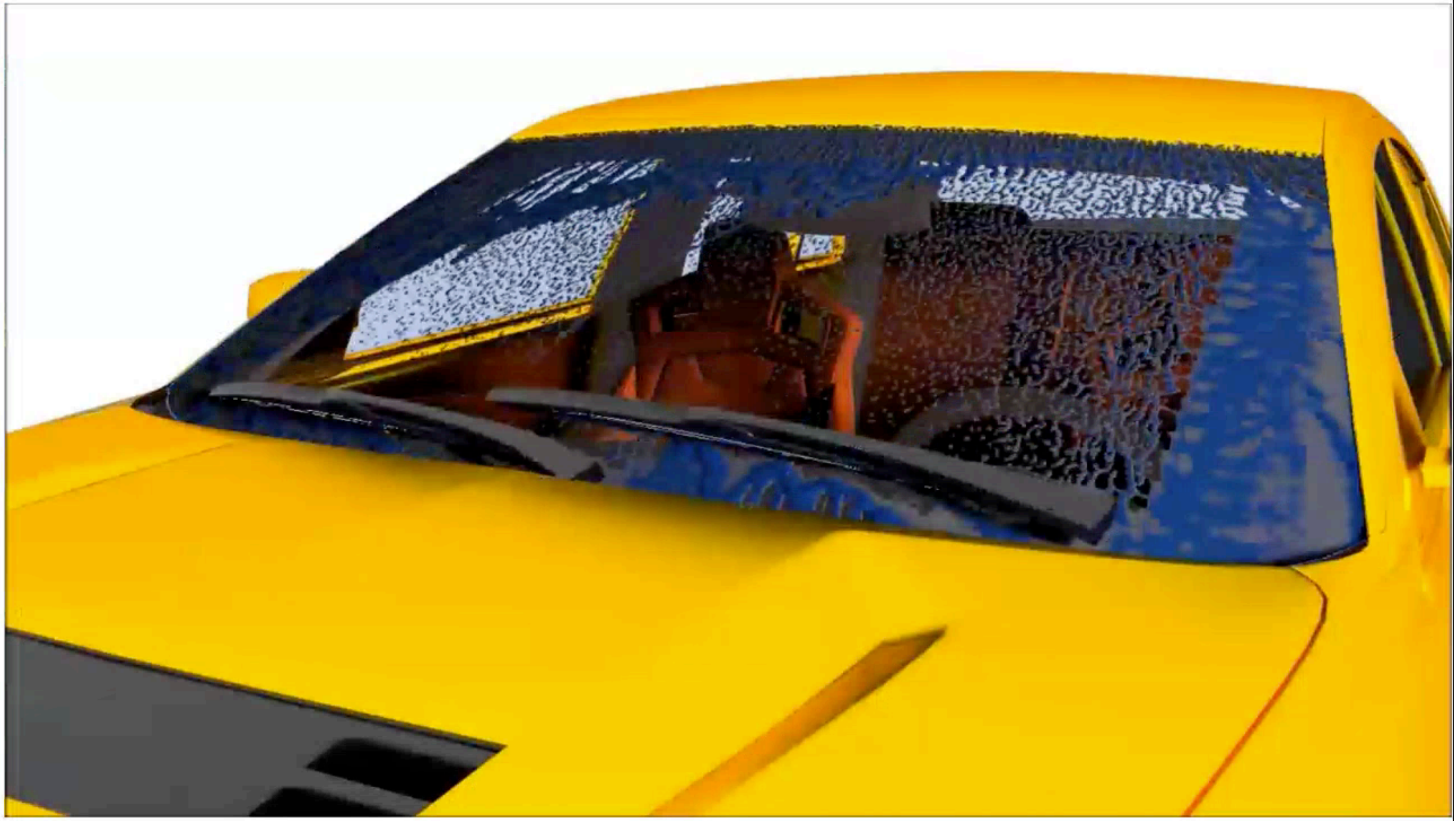

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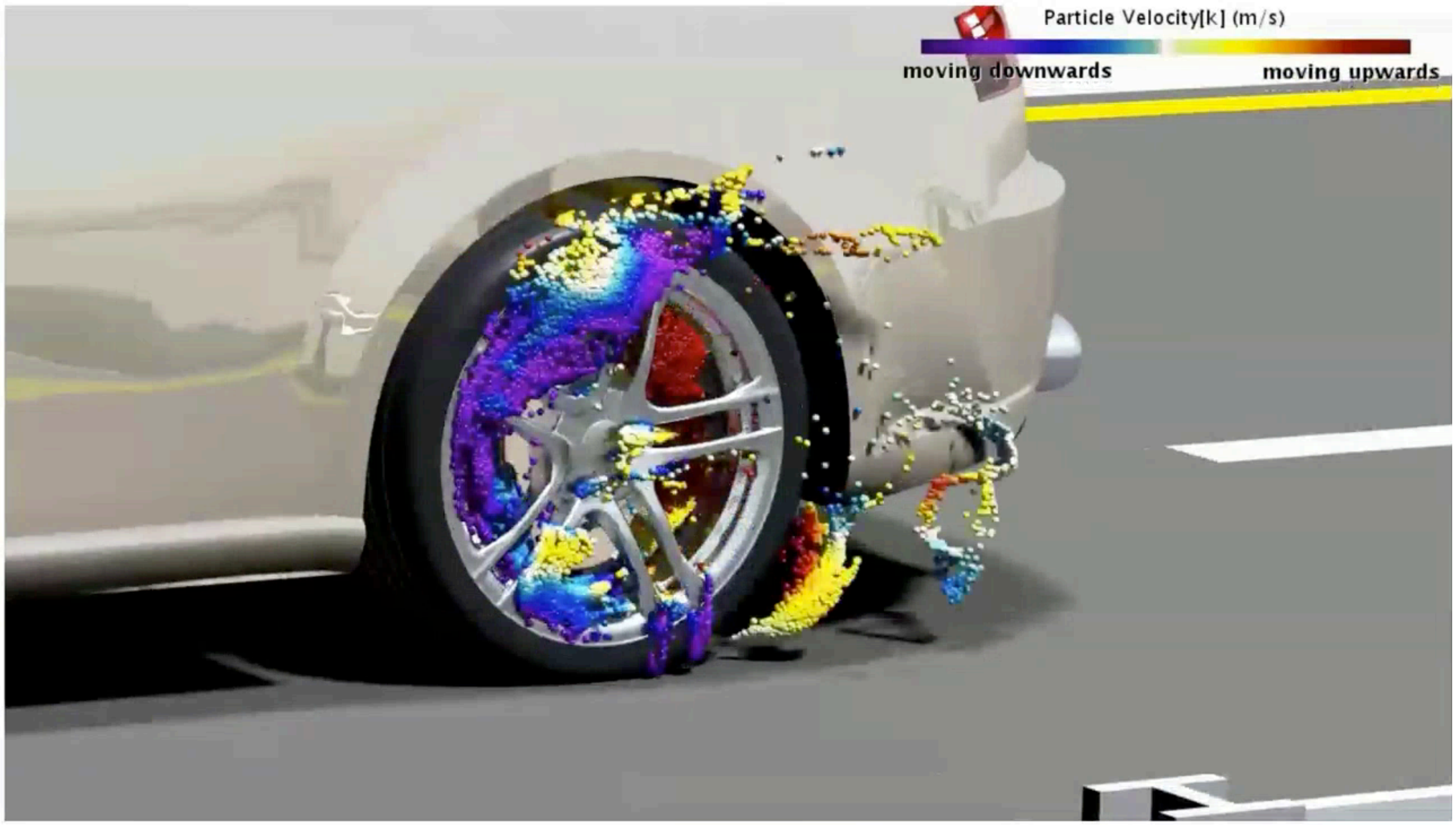

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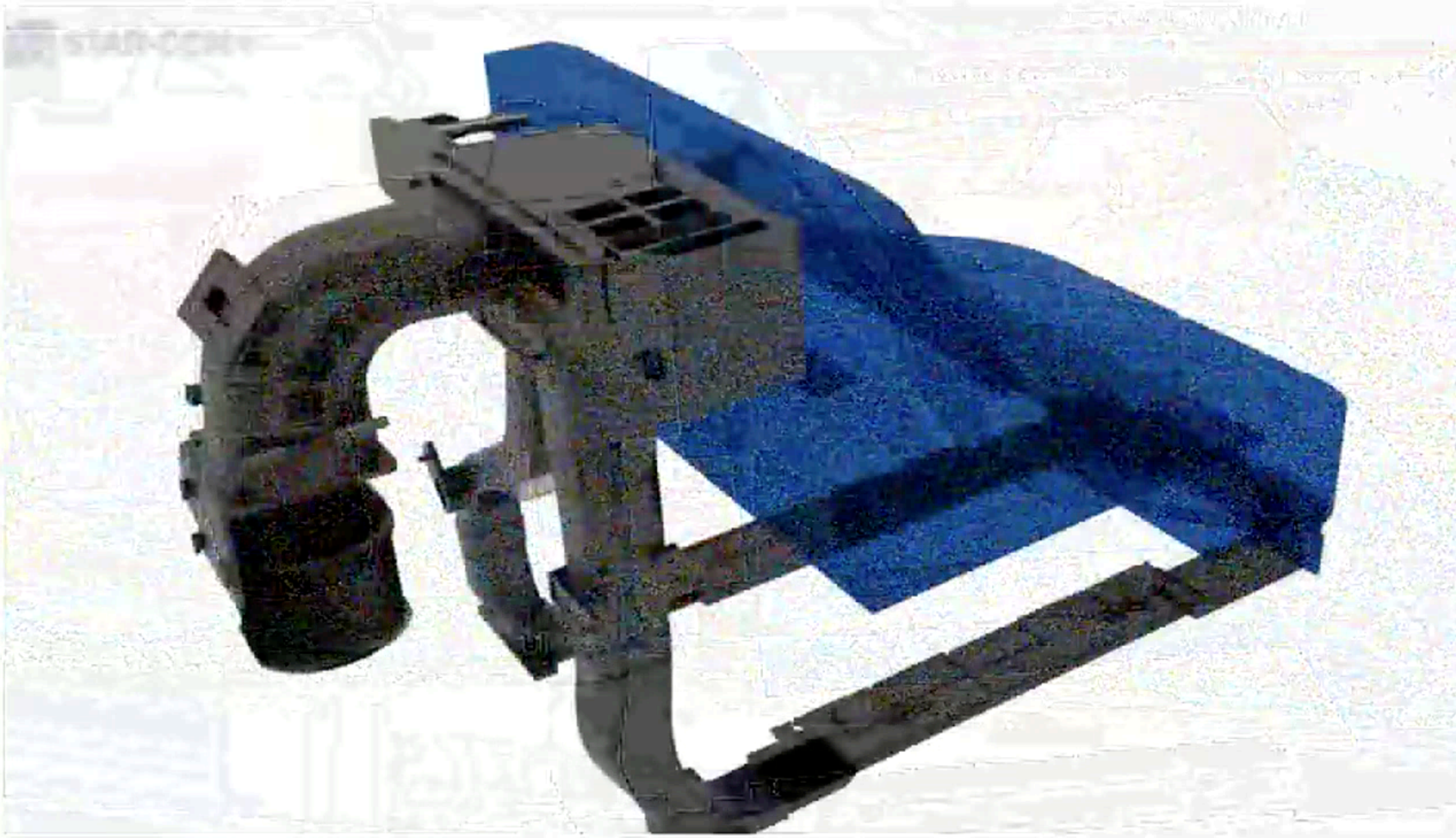

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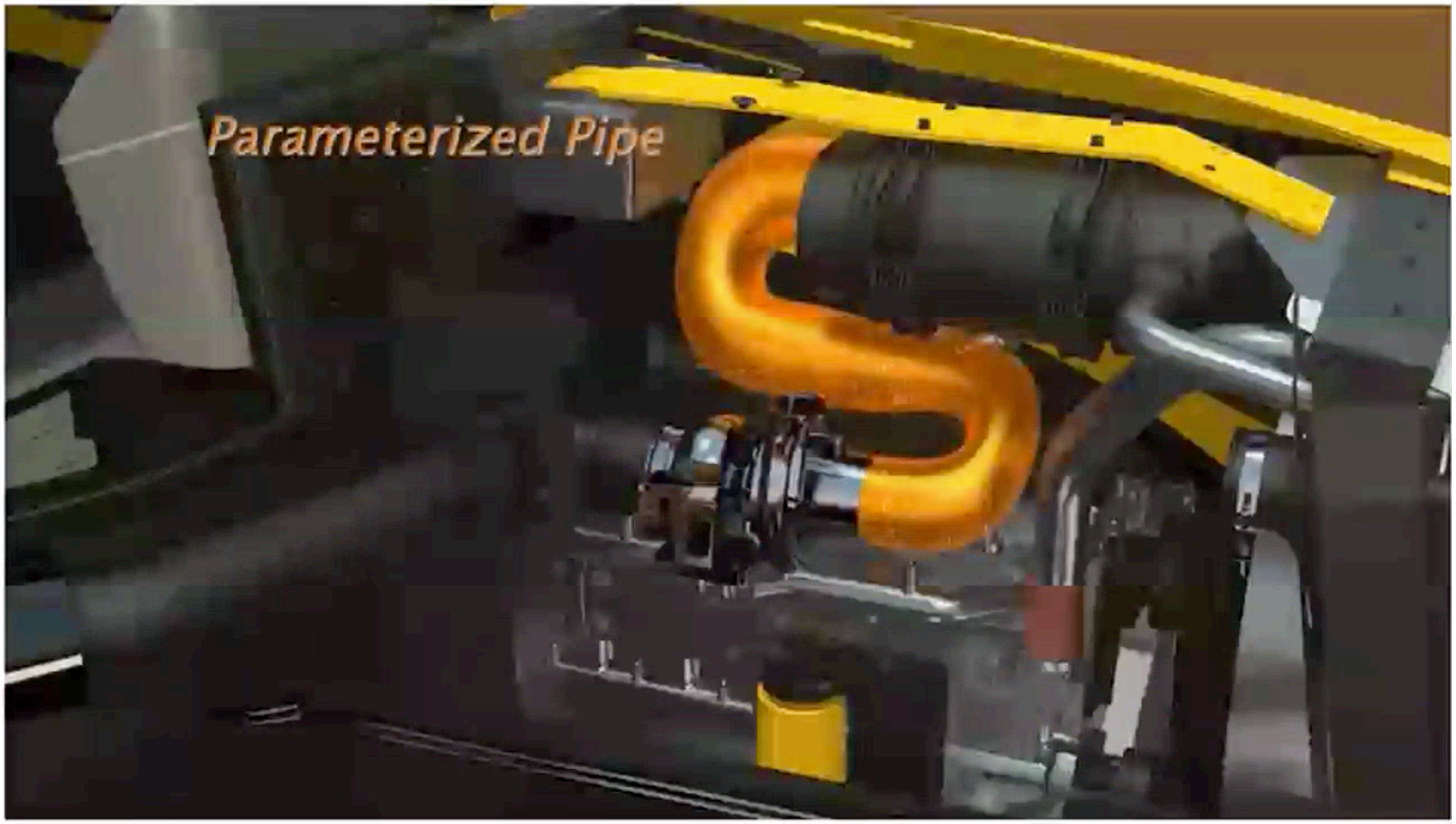

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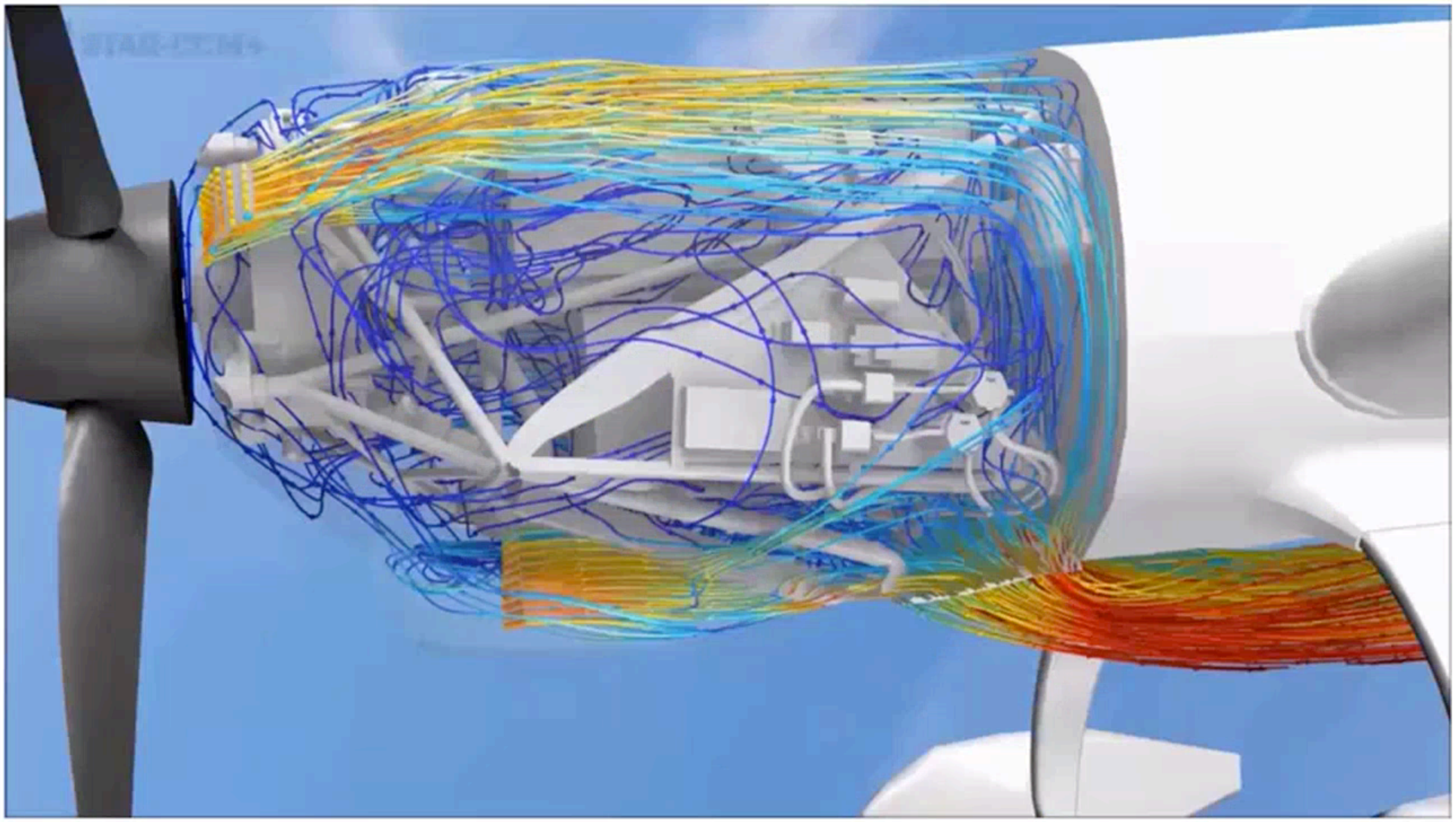

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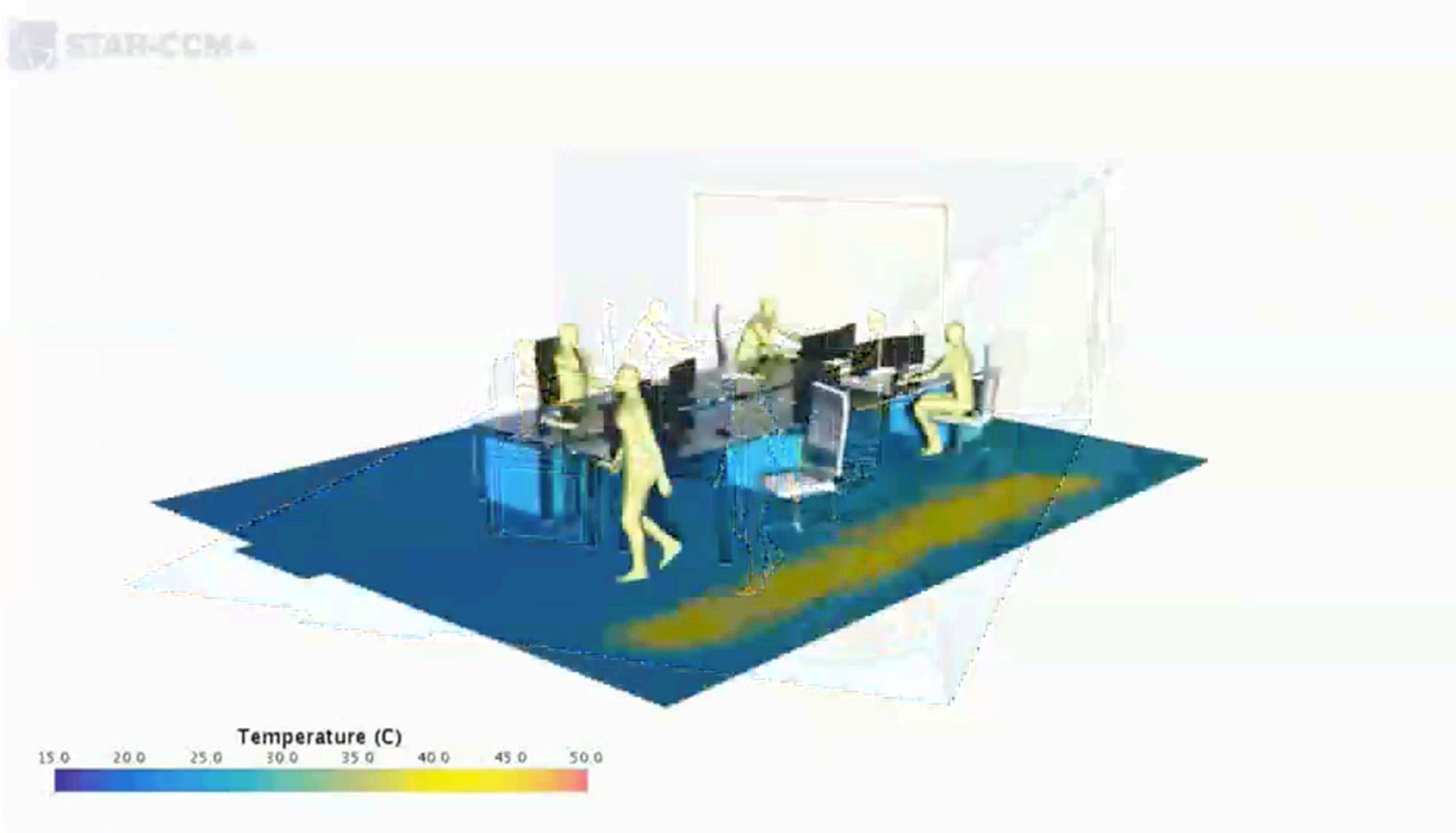

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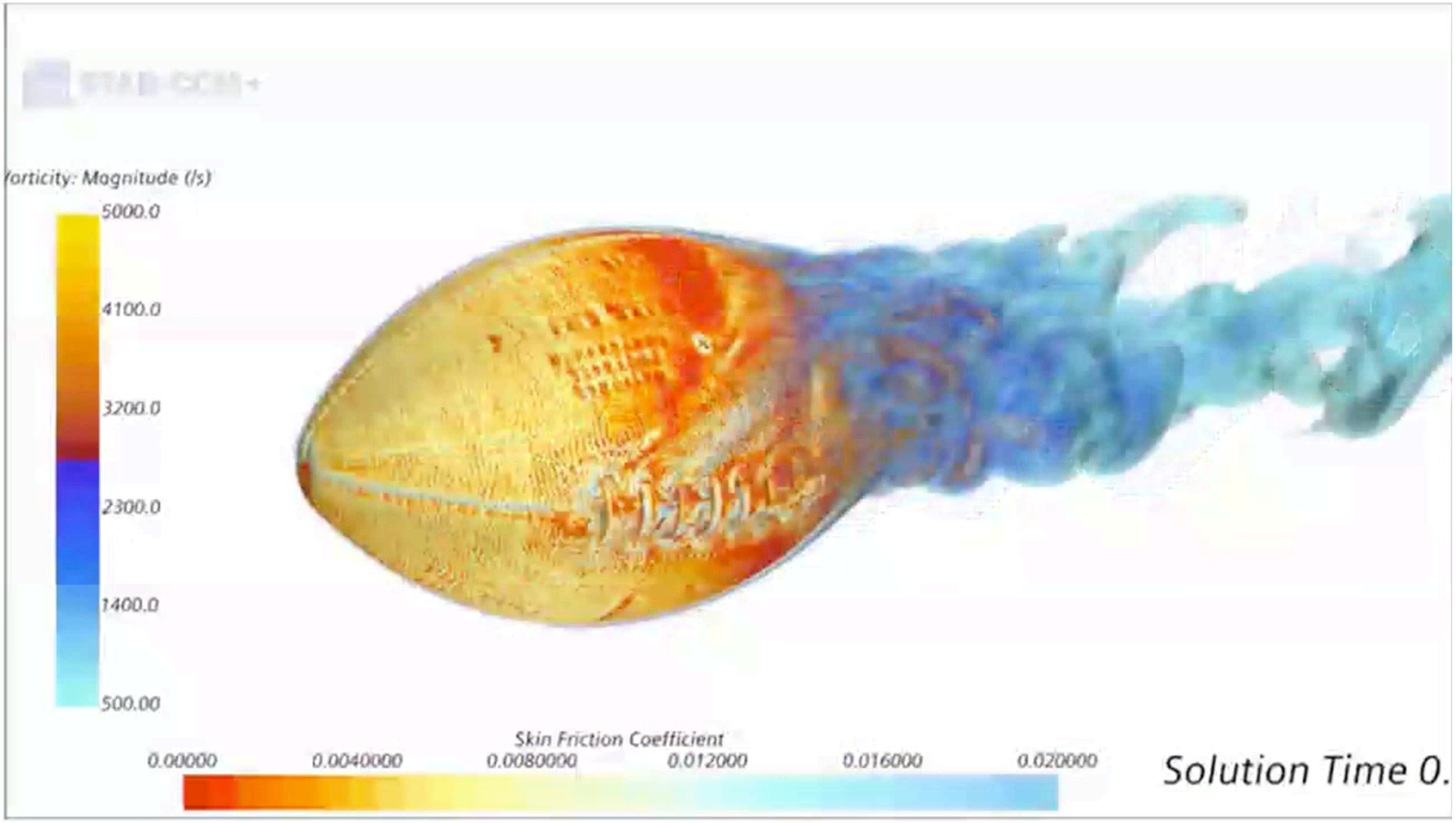

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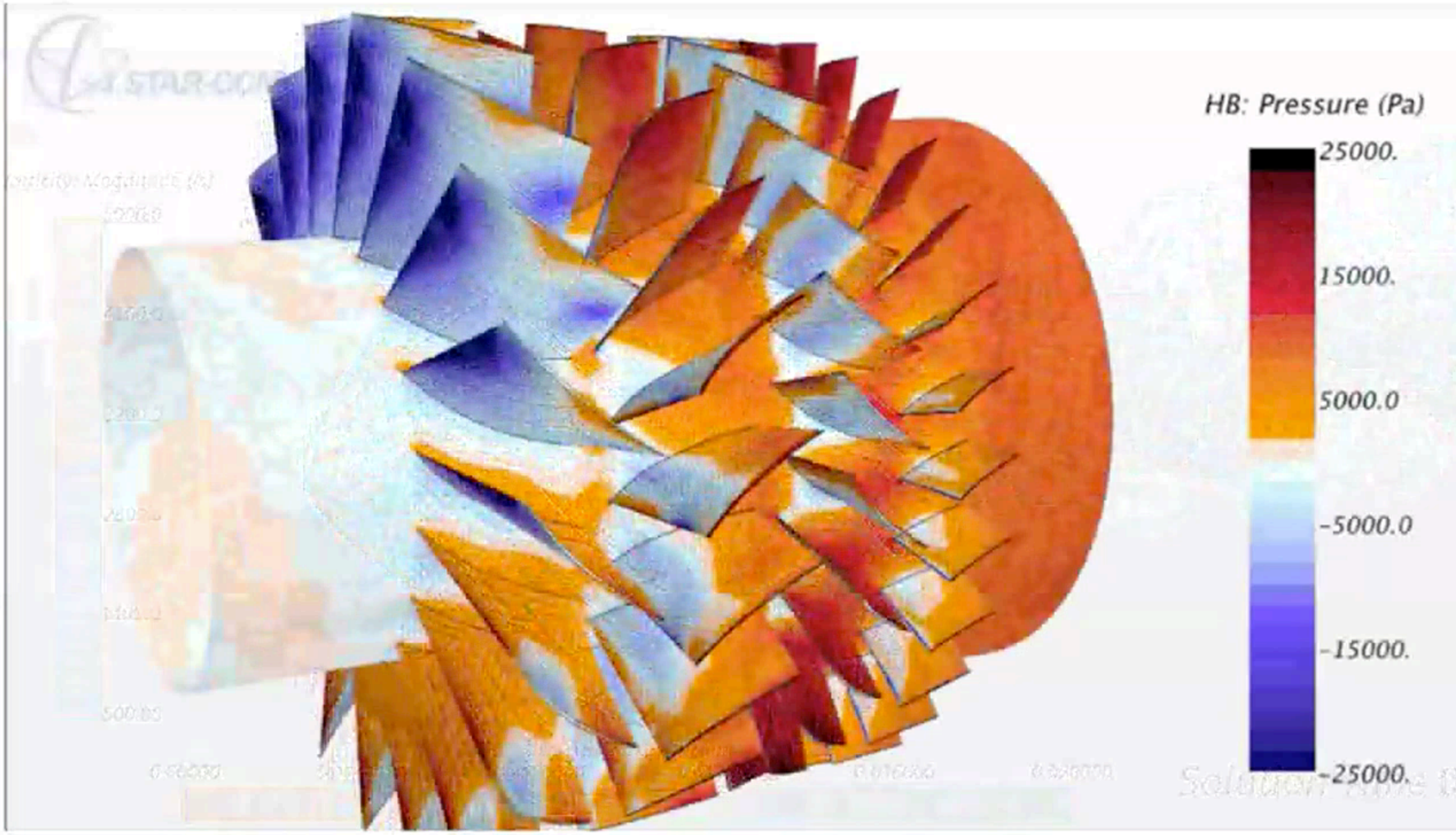

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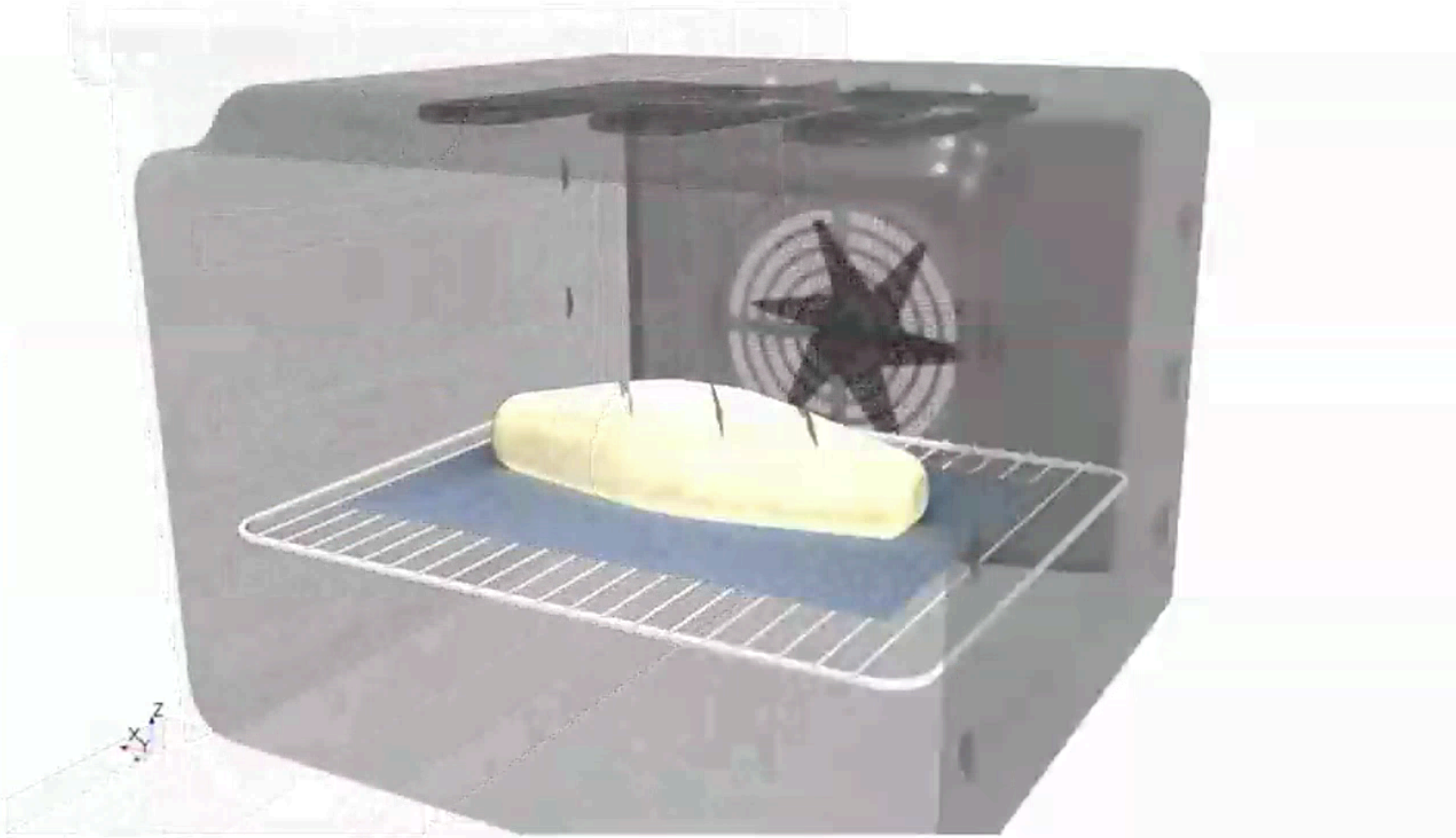

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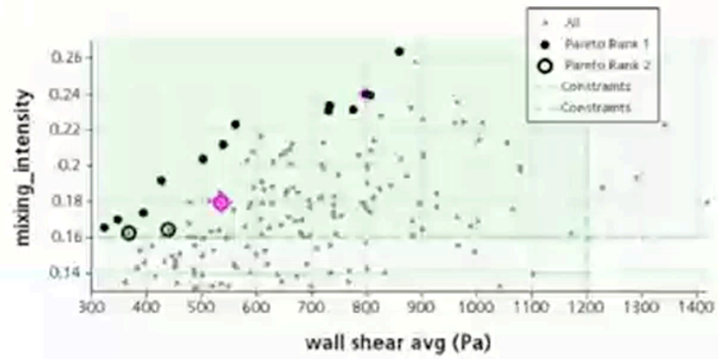

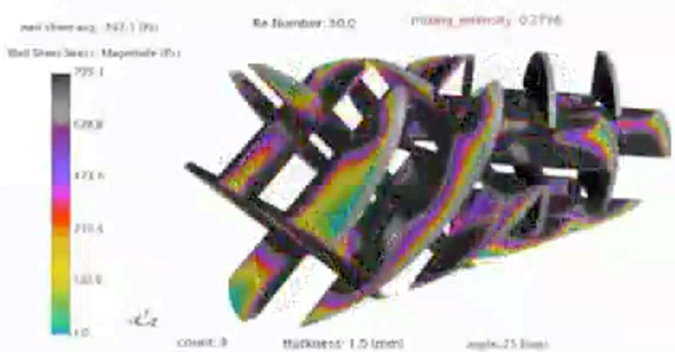

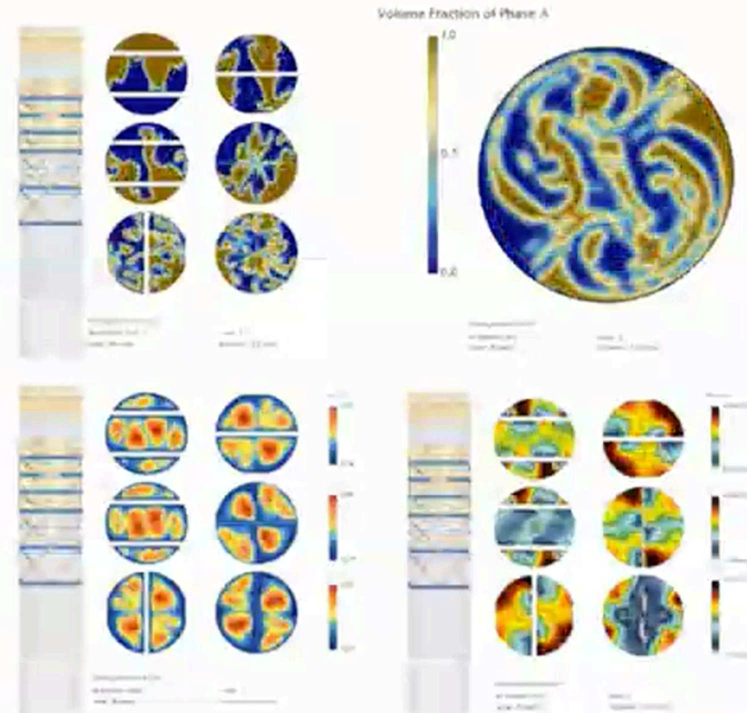

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Lagrangian multiphase model to simulate cough droplets

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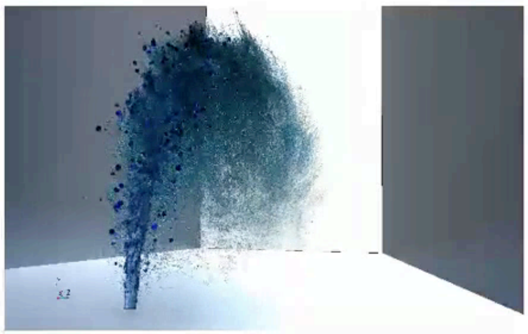

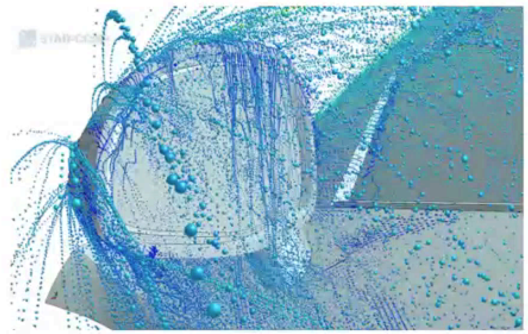

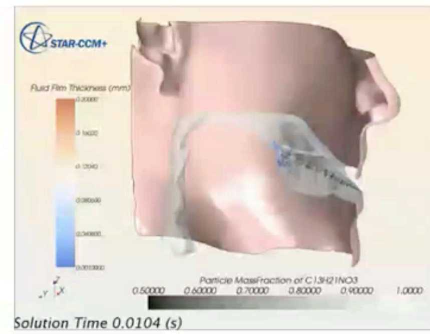

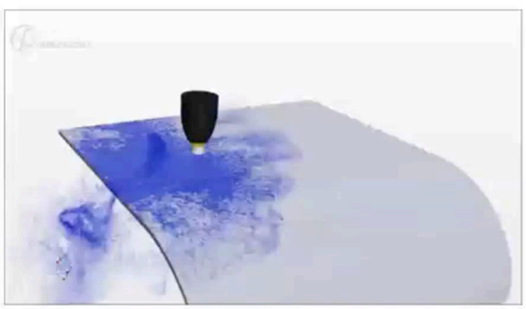

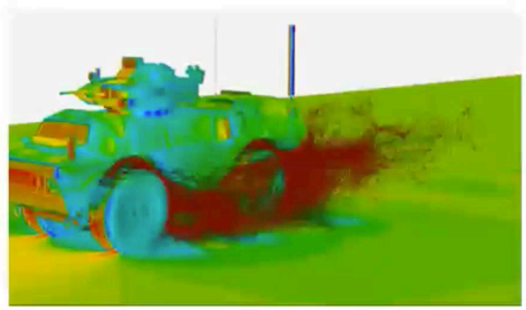

- **Lagrangian Multiphase (LMP)**
  - The observer tracks parcels of particles as they move through space & time.

  - One or two way coupled with airflow.
  - Impingement model allows both bounce or stick conditions.

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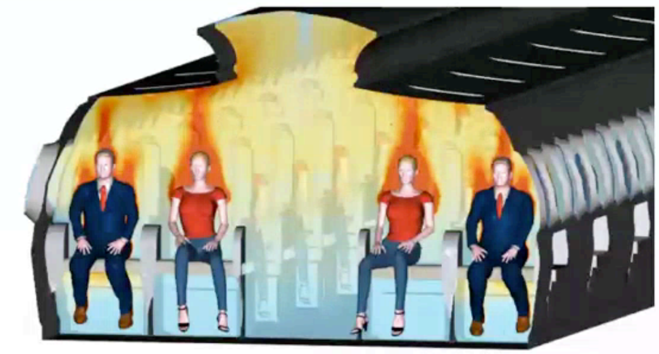
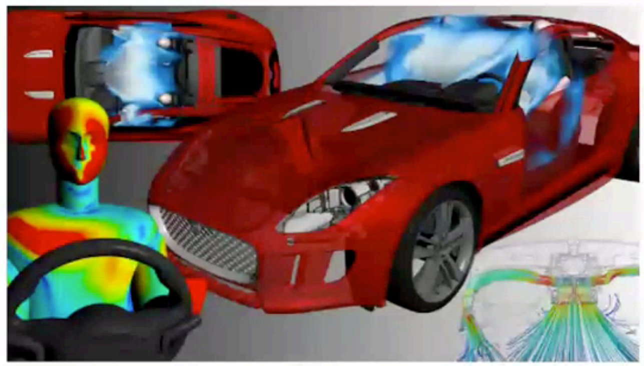
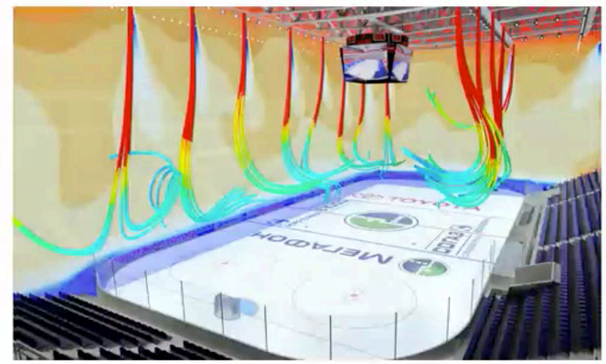
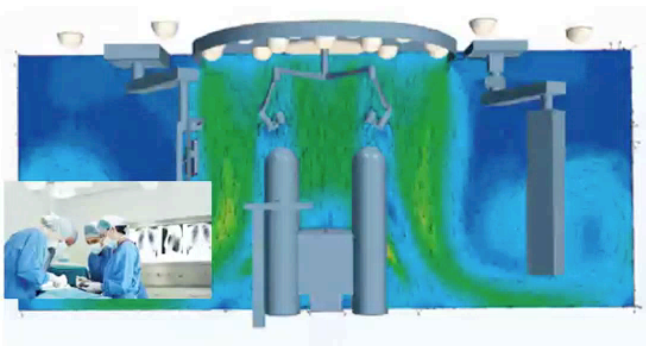
CFD simulation for ventilation and comfort studies

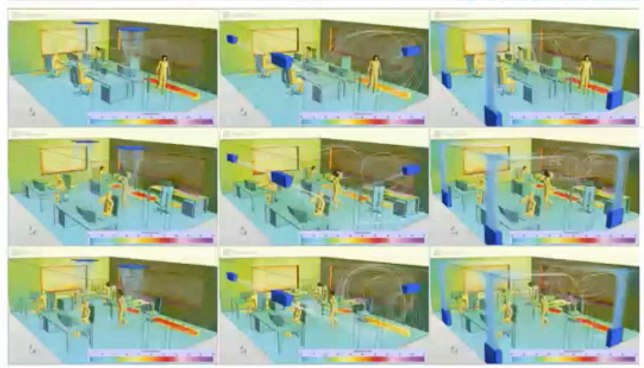
Airflow in confined spaces simulated for passenger comfort or ventilation system design

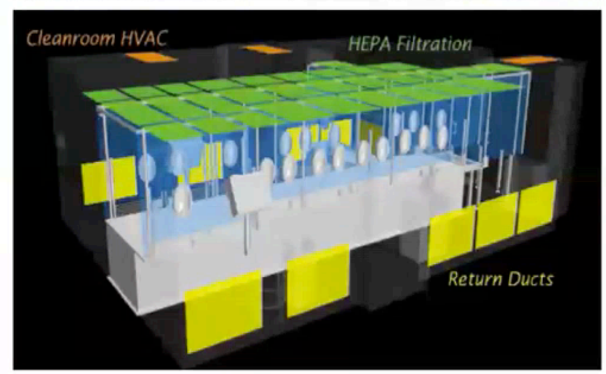












Cabin air flow

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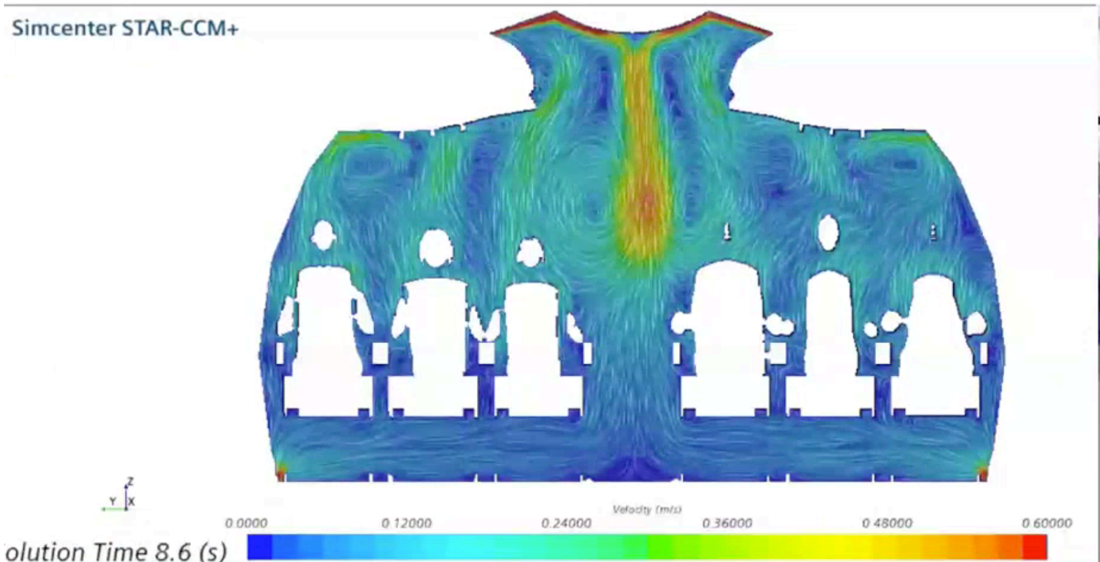
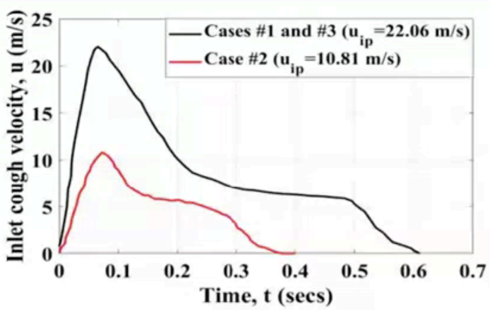


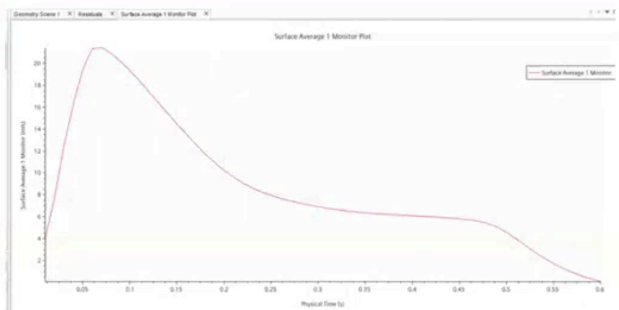
URANS run for 2-4 mins
Humidity 10% in cabin
Human models from Siemens Jack software
Temperature set for head/body

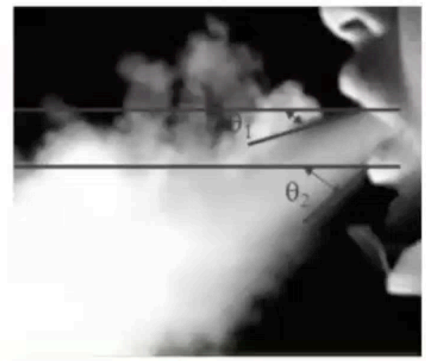
Thermal comfort modeling
Respiration from nose
Gaspers on/off
Mitigation efforts (barriers, shields)

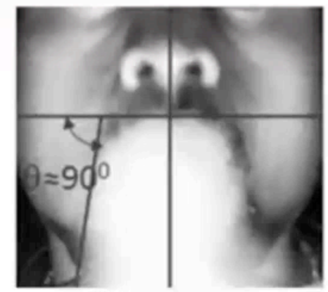
Cough jet profile

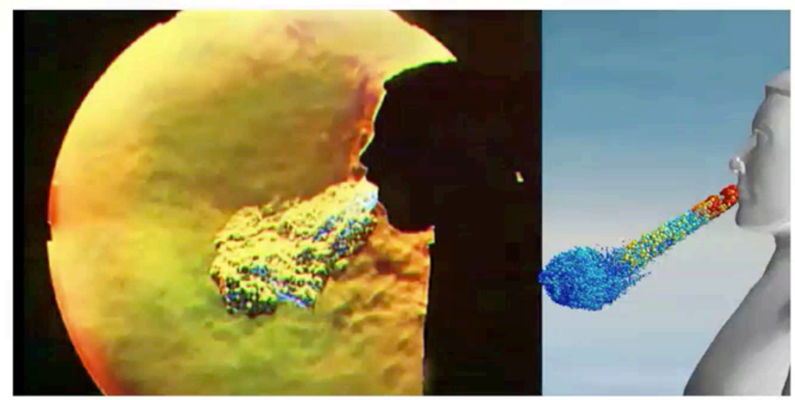
Test	Simcenter STAR-CCM+











Model the time-dependent cough jet velocity
Multicomponent – Air (94%) + water vapor (6%)
Non-evaporative 6%
Representative angle
Averaged mouth opening area = 4 sq. cm

Droplet distribution, tracking and evaporation

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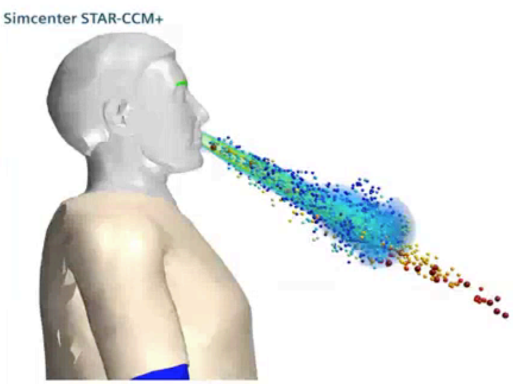

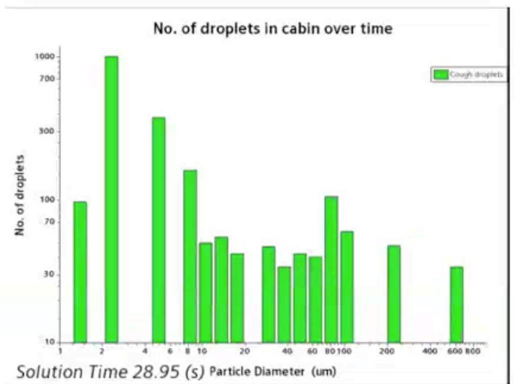

Table 3.2: Droplet size distribution (reproduced from Duguid (1946)).

Diameter class, μm	Number of droplets (N)	Mass flow rate, kg/sec
3	76	1.07442e-9
6	1041	1.17621e-7
12	386	3.43816e-7
20	127	5.27788e-7
28	47	5.28726e-7
36	45	1.07488e-6
45	38	1.81309e-6
62.5	38	4.85761e-6
87.5	27	9.12003e-6
112.5	32	2.38565e-5
137.5	30	4.08346e-5
175	83	2.35718e-4
225	47	2.74349e-4
375	40	1.10447e-3
750	27	5.74322e-3
Total	2084	7.44083e-3

No. of droplets in a cough = 2000 – 10,000
Diameter range = 0.1 – 750 micron
Injection time = 0.042 – 0.136 sec
Drag, gravity, thermophoresis, Stokes

Evaporation, inertia, gravity and drag
Humidity in cabin (10%) and cough jet (80-90%)
Droplet tracking – 2 – 4 minutes

Single cough vs statistical (Empty room)
What you see is not what happens

128 compute cores
Under 1 day for airflow + cough computation

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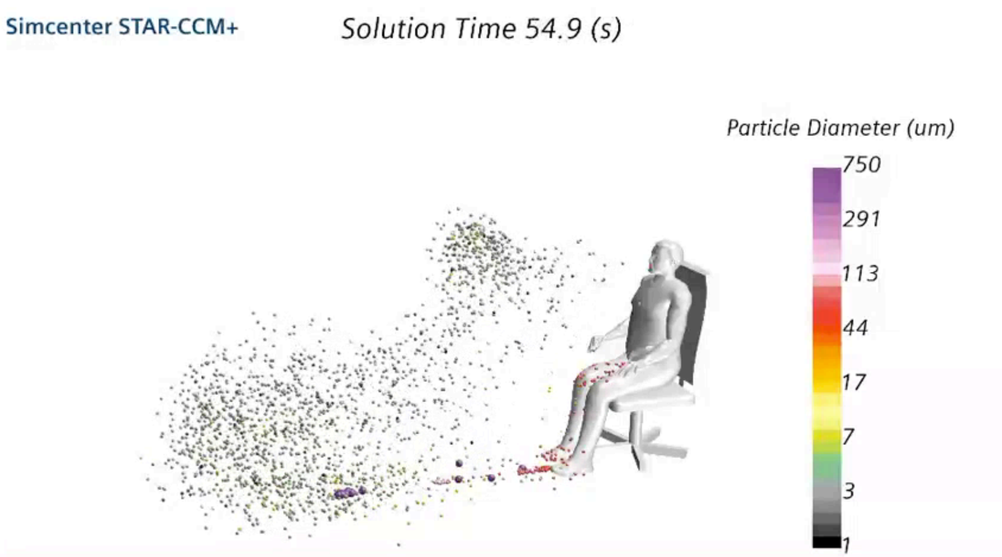

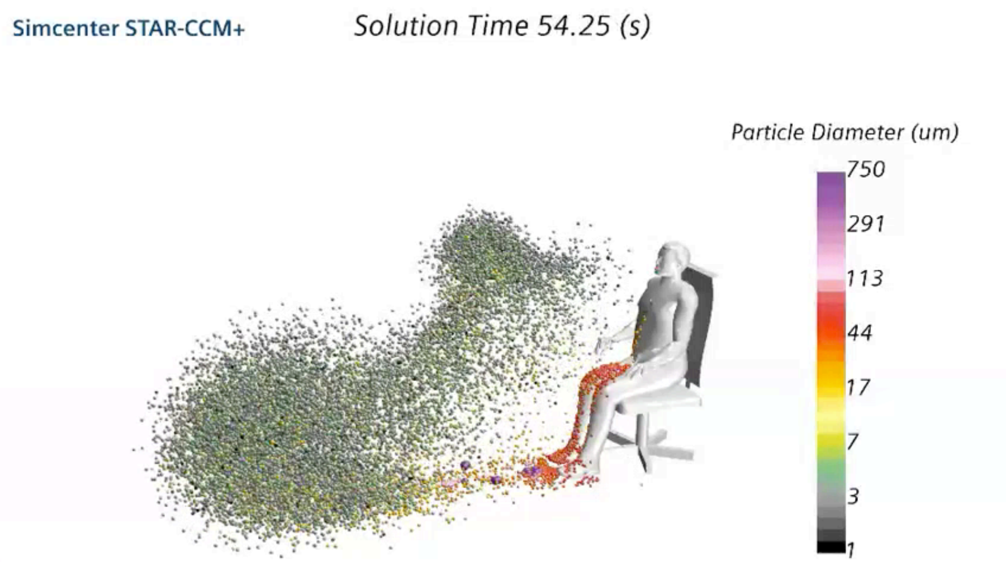

Modeling exact no. of particles (2084)
Realistic representation

Parcel approach usually used for large no. of droplets
Ex: 1e6 droplets represented by 1e3 parcels

Reducing droplet transmission
Masks – our greatest ally

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Source: New York Times

Mask Type	Standards	Filtration Effectiveness		
Single-Use Face Mask 	**China:** YY/T0969	3.0 Microns: ≥95% 0.1 Microns: ✗		
Surgical Mask 	**China:** YY 0469	3.0 Microns: ≥95% 0.1 Microns: ≥30%		
	USA: ASTM F2100	Level 1	Level 2	Level 3
		3.0 Microns: ≥95% 0.1 Microns: ≥95%	3.0 Microns: ≥98% 0.1 Microns: ≥98%	3.0 Microns: ≥98% 0.1 Microns: ≥98%
	Europe: EN 14683	Type I	Type II	Type III
		3.0 Microns: ≥95% 0.1 Microns: ✗	3.0 Microns: ≥98% 0.1 Microns: ✗	3.0 Microns: ≥98% 0.1 Microns: ✗
Respirator Mask 	**USA:** NIOSH (42 CFR 84) **China:** GB2626	N95 / KN95	N99 / KN99	N100 / KN100
		0.3 Microns: ≥95%	0.3 Microns ≥99%	0.3 Microns ≥99.97%
	Europe: EN 149:2001	FFP1	FFP2	FFP3
		0.3 Microns: ≥80%	0.3 Microns: ≥94%	0.3 Microns: 99%

3.0 Microns: Bacteria Filtration Efficiency standard (BFE).
0.1 Microns: Particle Filtration Efficiency standard (PFE).
0.3 Microns: Used to represent the most-penetrating particle size (MPPS), which is the most difficult size particle to capture.
✗: No requirements.

Modeling a mask
Challenges

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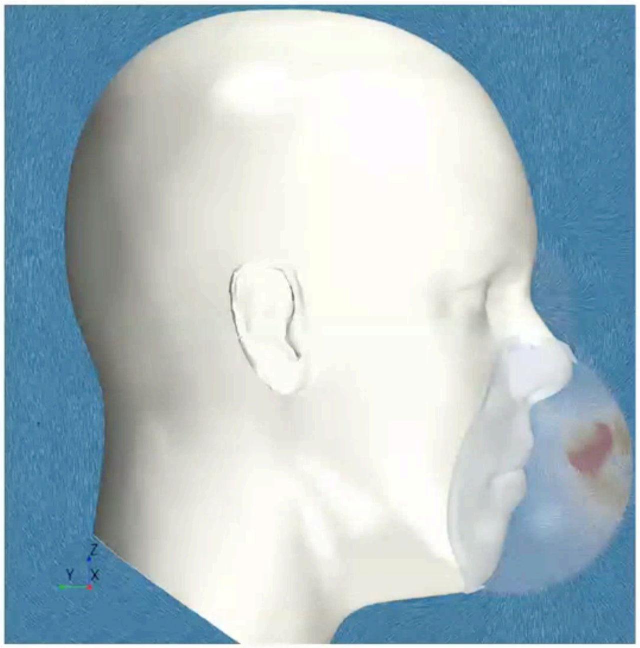
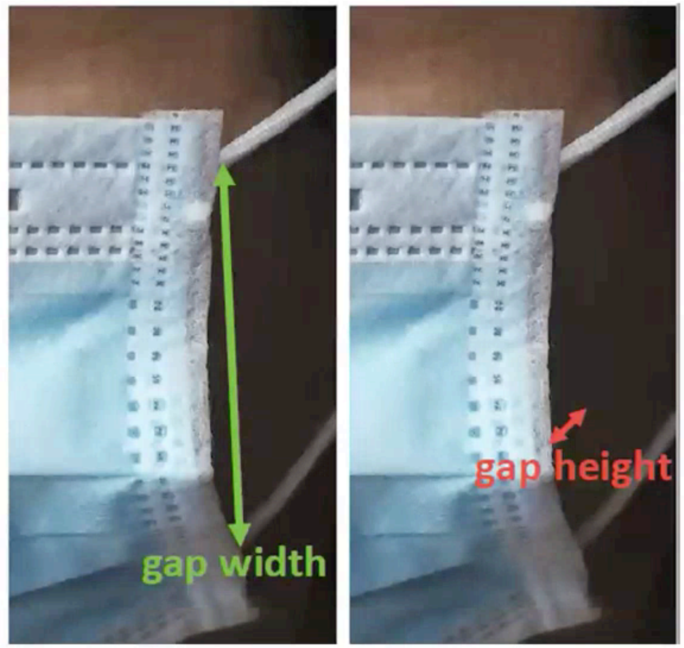
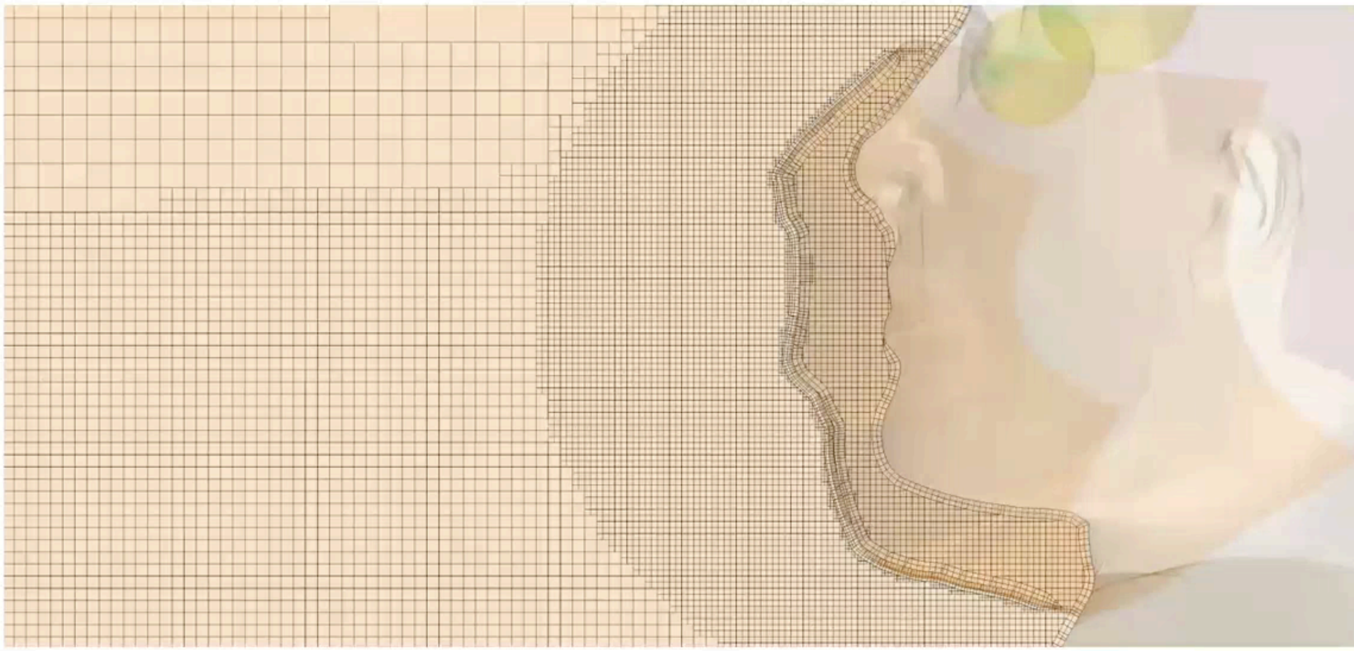




Diameter	Efficiency
4.00E-07	0.4
8.50E-07	0.5
9.50E-07	0.6
1.50E-06	0.9
2.50E-06	0.95
3.50E-06	0.95
4.50E-06	0.95
7.50E-06	0.98
1.25E-05	0.99
1.75E-05	0.99
2.25E-05	1
1.00E-03	1

Analytical and numerical investigation of the airflow in face masks used for protection against COVID-19 virus – implications for mask design and usage
R. Peric´ 1† and M. Peric´ 2

Modeling a mask
Challenges



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2.50E-06	0.95
3.50E-06	0.95
4.50E-06	0.95
7.50E-06	0.98
1.25E-05	0.99
1.75E-05	0.99
2.25E-05	1
1.00E-03	1

Analytical and numerical investigation of the airflow in face masks used for protection against COVID-19 virus – implications for mask design and usage
R. Peric´ 1† and M. Peric´ 2

Simulating a single cough(Empty room)

No mask vs mask

Coughing without a mask
Realistic representation of a single cough

Mask modeled as a baffle interface
Gaps on the sides, top and bottom modeled
Filtration efficiency assumed from triple layer masks
viscous porous resistance, Cm = 2000m/s u

Airbus / Siemens

CFD simulation of cough droplet propagation in aircraft cabin

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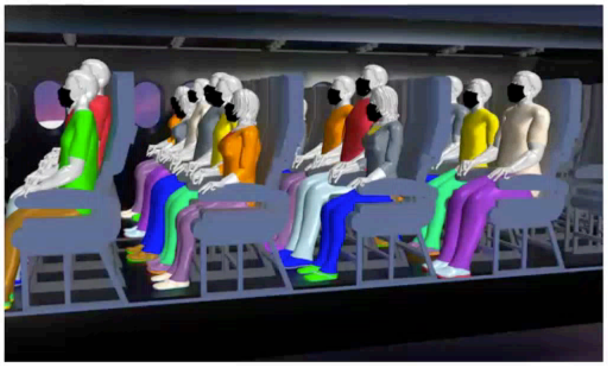
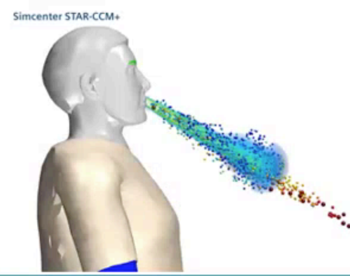


Understanding transport of particles from a human cough in aircraft cabin



Simulation without a mask

Simulation with a mask

- **Simulation of cough in aircraft cabin**
- **With/without a mask**
- **Asynchronous breathing included**
- **Risk assessment indicators in cabin**
- **Validated aerothermal cabin airflow used**

- Leaving middle seat open doesn’t change risk factor
- With mask, less than 1% particles remain airborne in less than 2 minutes

KPIs:

- **Counting inhaled particles per passenger**
- **Particle size characterization**
- **Particles in breathing zone**
- **Time to reach <1% airborne particles**

Courtesy: https://www.plm.automation.siemens.com/global/en/webinar/high-fidelity-cough-simulation/78865

Medevac Cabin Analysis – UES/USAF
Identify bioaerosol contamination to safely airlift COVID-19 patients

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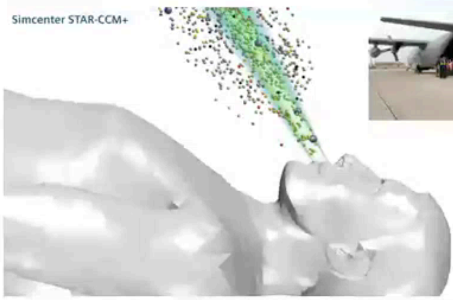
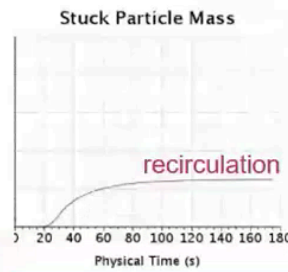


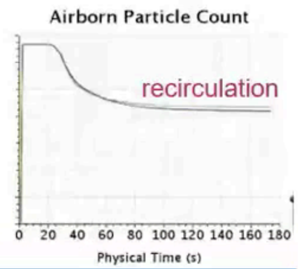
www.acc.af.mil/News

- **C-130 aircraft scenario**
- **200 CPUs in a few days**
- **Transient multi-phase cabin with +100,000 Lagrangian particles**
- **Solve quickly using High Performance Computing cluster**
- **Infected passengers on beds**
- **Simcenter Engineering Services**

Droplets from sick passenger injected and tracked throughout the aircraft cabin using Simcenter STAR-CCM+ multi-phase functionality

Simulation tracks particles in time and predicts where different size particles land





Particle incident mass and resonance times predicted

- Output aides in the design of the cabin ventilation & aircrew safety procedures
- Helped identify contamination hotspots for disinfection purposes

> **"The airflow study enables mission planners to understand and visualize how the air and any biological contaminants will move inside the cargo aircraft and best mitigate the risks. This data makes in-patient transfer and overall Air Force personnel transport safer for all involved"**
>
> **UES**

https://www.plm.automation.siemens.com/global/en/our-story/customers/ues-simcenter/90375/

Heraeus Noblelight
Designing a 99.99% efficient UV-C purifier with CFD

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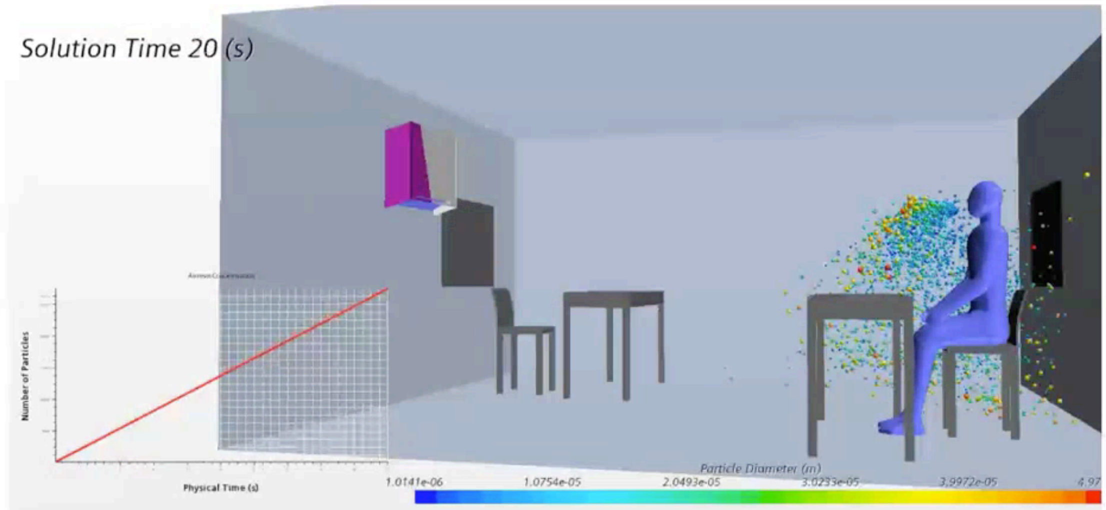
- **New device designed and validated with simulation**
- **Experiments proved 99.99% purification efficiency**
- **Droplet simulation with Simcenter STAR-CCM+ to assess device performance**
- **First device already fitted in regional bus**

Soluva UV-C air purifier designed with CFD simulation

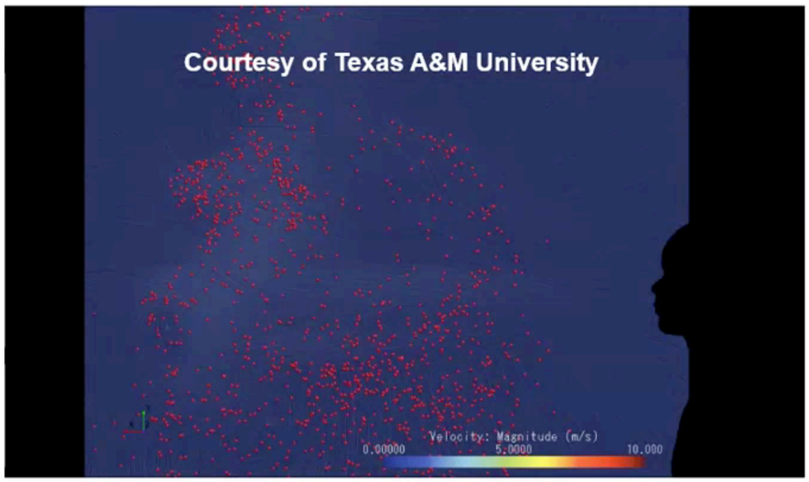


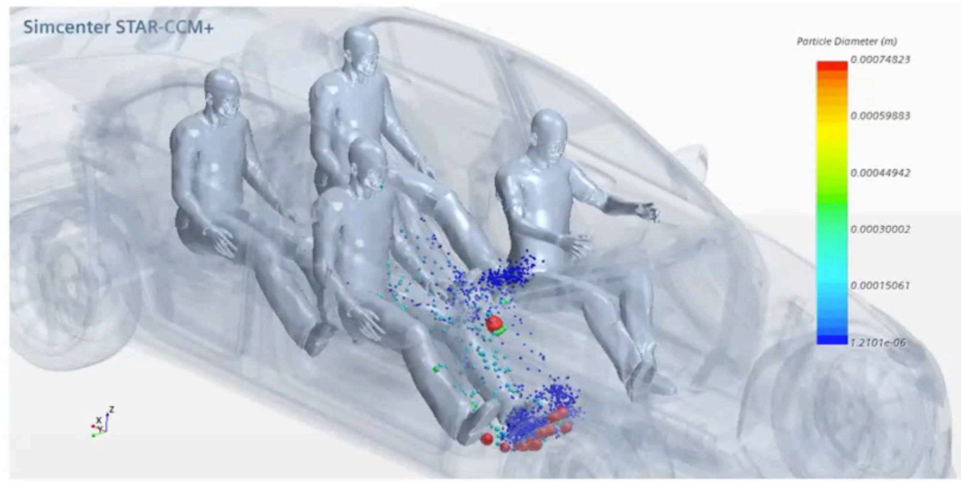
"It is much easier to first model a product in the virtual world than to physically assemble it directly. Thanks to the precise simulation, we saved many production steps and immediately knew what to look out for"

- Dr. Larisa von Riewel, CAE and simulation expert

Courtesy: https://www.heraeus.com/en/group/innovation/press_and_news_1/2020_4/virtual_simulation_air_disinfection.html

Cough/sneeze in other spaces
Industrial use cases





Keys to modeling a cough in an airplane accurately

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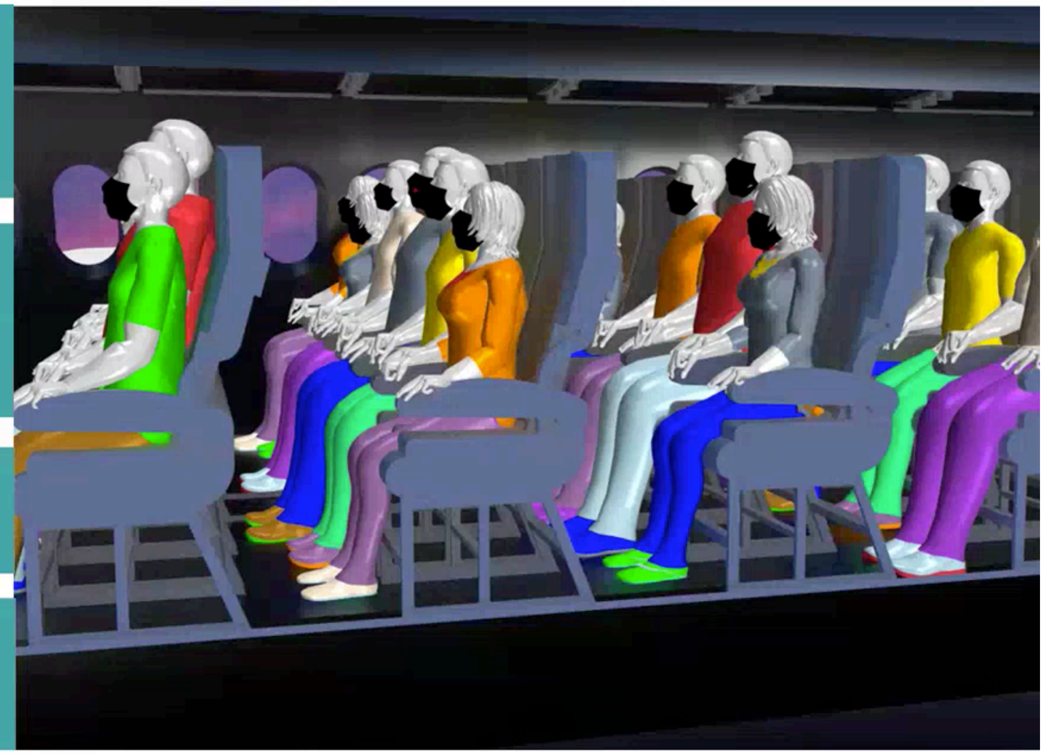
Diligent modeling to include as many relevant variables

Multiphysics CFD simulation approach to accurately model the scenarios

Proper representation of the cabin environment

Right approach to droplet tracking

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